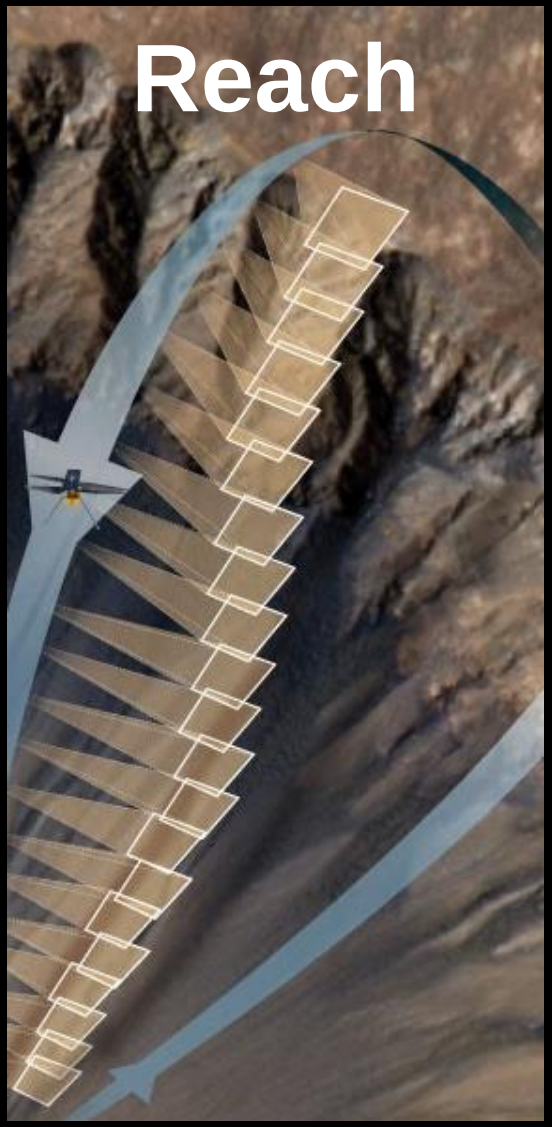
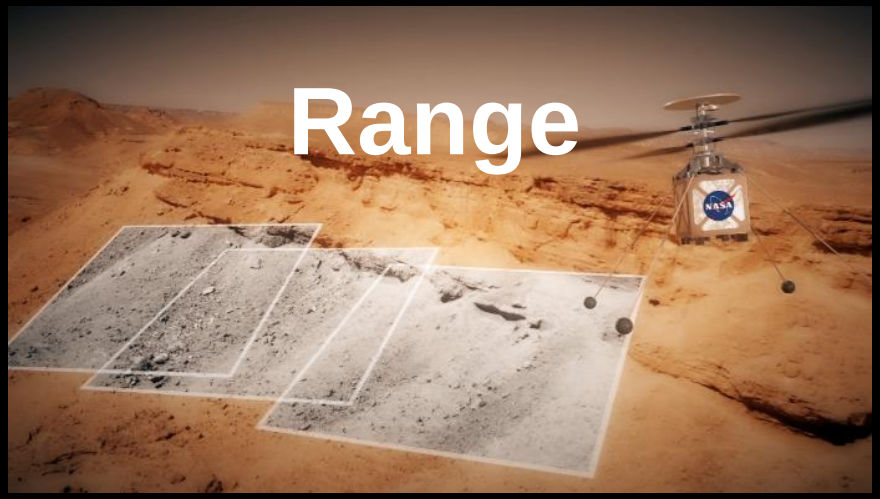
Mars Helicopter

J. (Bob) Balaram **Jet Propulsion Laborator, California Institute of Technology**

Why helicopters ?





What would they do ?

ROVER
SCOUT

LANDER
ASSISTANT

INDEPENDENT
EXPLORER

What makes it hard ?

The air on Mars is very thin with a density of only 1% of that at the Earth's surfac
It's like being at a 100,000 feet on Earth

Mars is very far away making communication and operations a challenge.
It can take up-to 20 minutes to get a radio signal transmitted to or from Mars

Mars can get very cold at night at -90ºC
Structures and electronics can break and batteries can freeze

The helicopter has to be both an aircraft and a spacecraft
Vibrations, g-forces, vacuum and radiation not typically seen by an aircraft

The helicopter has to hitch a ride on a flagship mission
Need to be safe to the rover and very, very clean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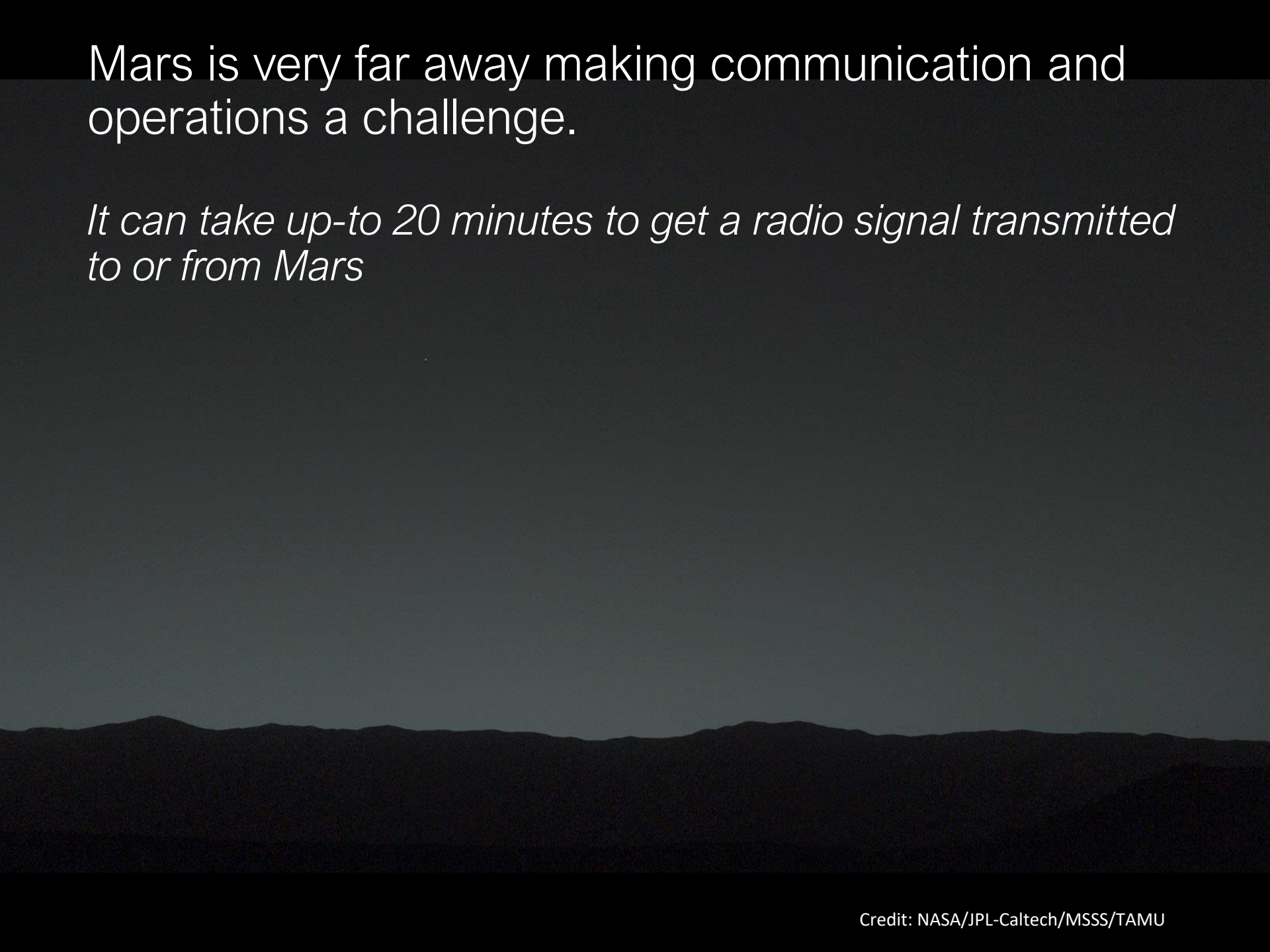

Credit: NASA/JPL-Caltech/MSSS/TAMU


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https://mars.nasa.gov/mars2020/mission/launch-vehicle/

The helicopter has to hitch a ride on a flagship mission

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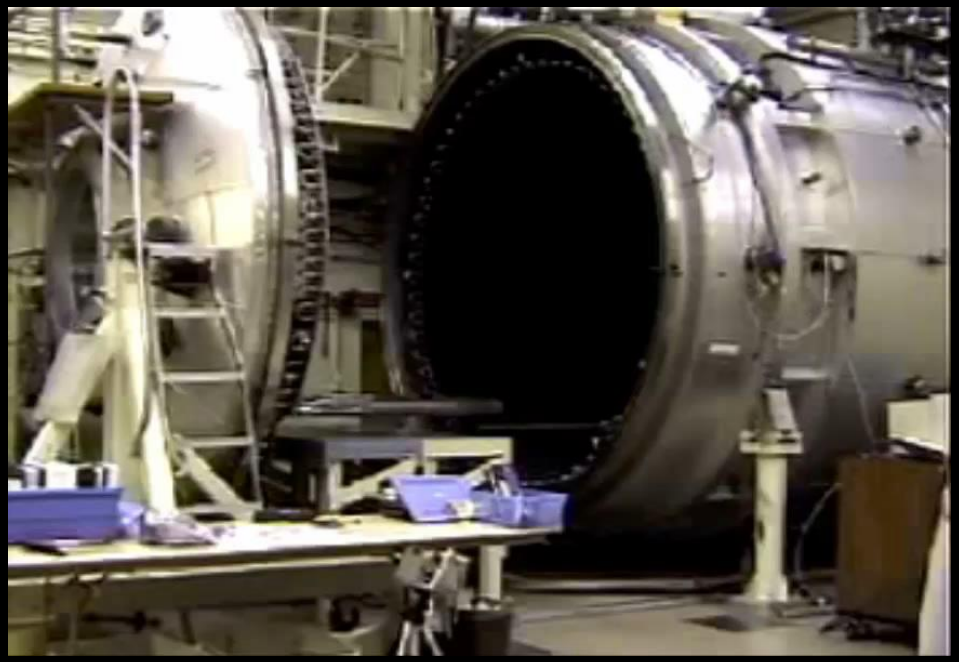
https://mars.nasa.gov/mars2020/mission/launch-vehicle/

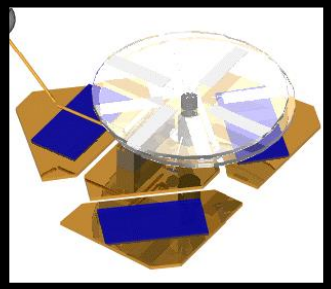
The birth ….

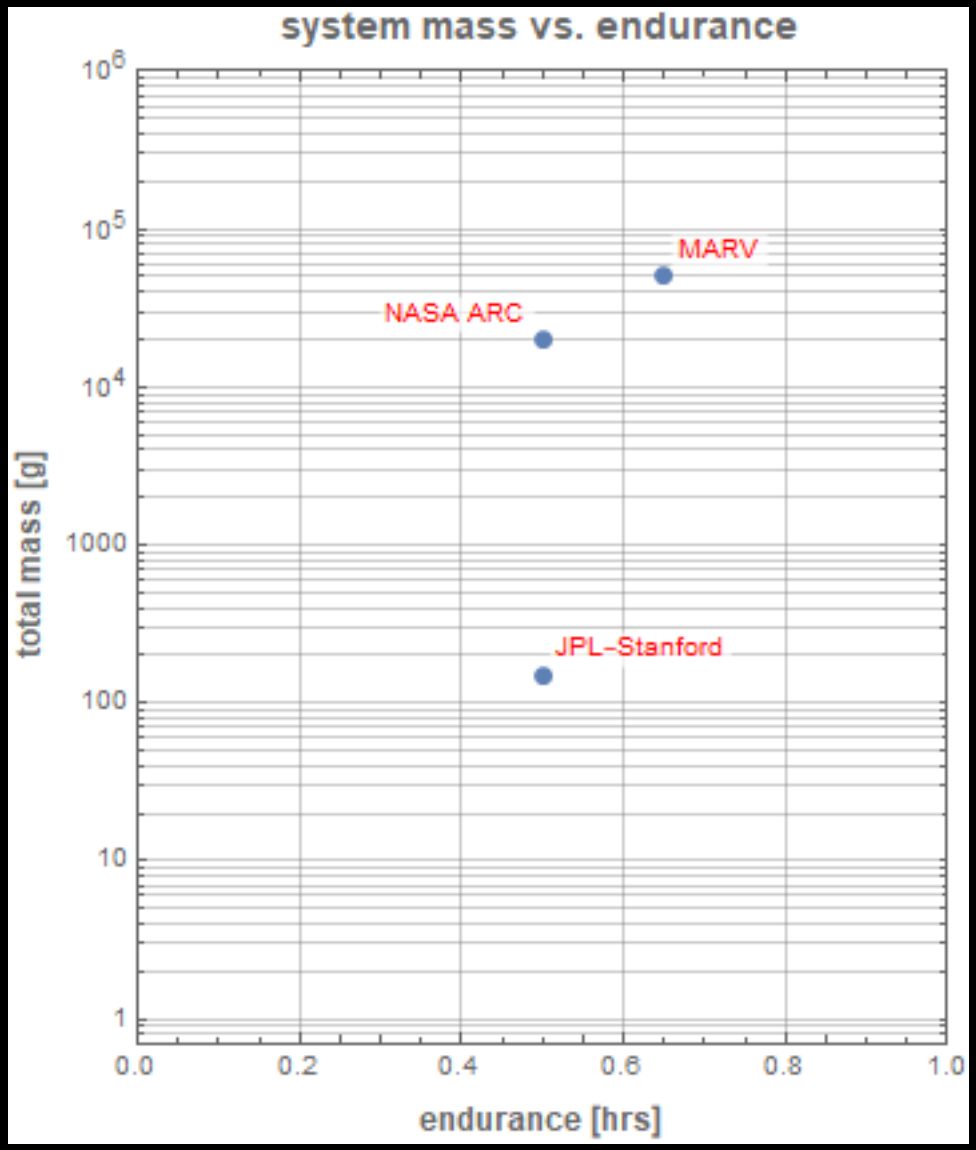
July 1999
Rotor-on-a-pivot



Early Rotorcraft Designs

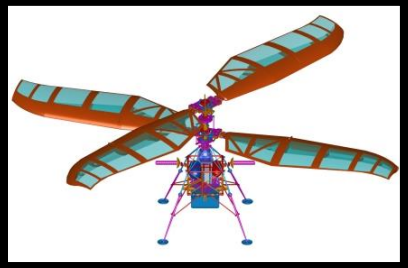
NASA ARC
2000-2005
R_{eff} = 1.7m





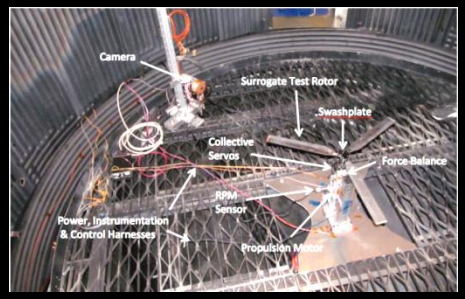
American Helicopter Society Student Competition Winner

University of Maryland
2000
R_{eff} = 2.15 m

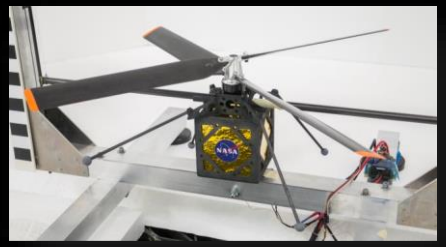


JPL-Stanford
1999
R_{eff} = 0.13m

Rotor development starts



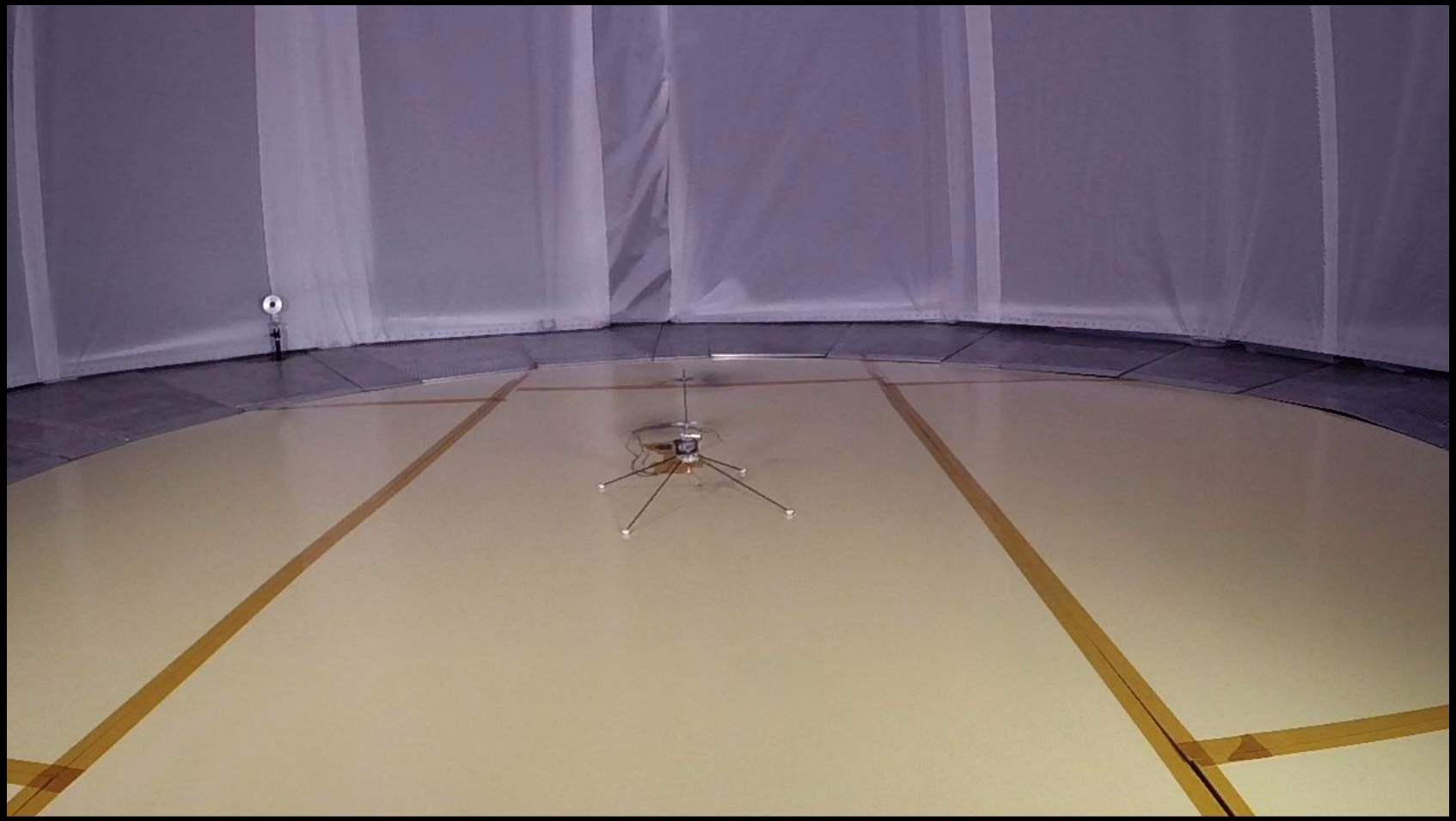
Dec 2013
Rotor-aero



March 2014
Rotor-on-a-rail

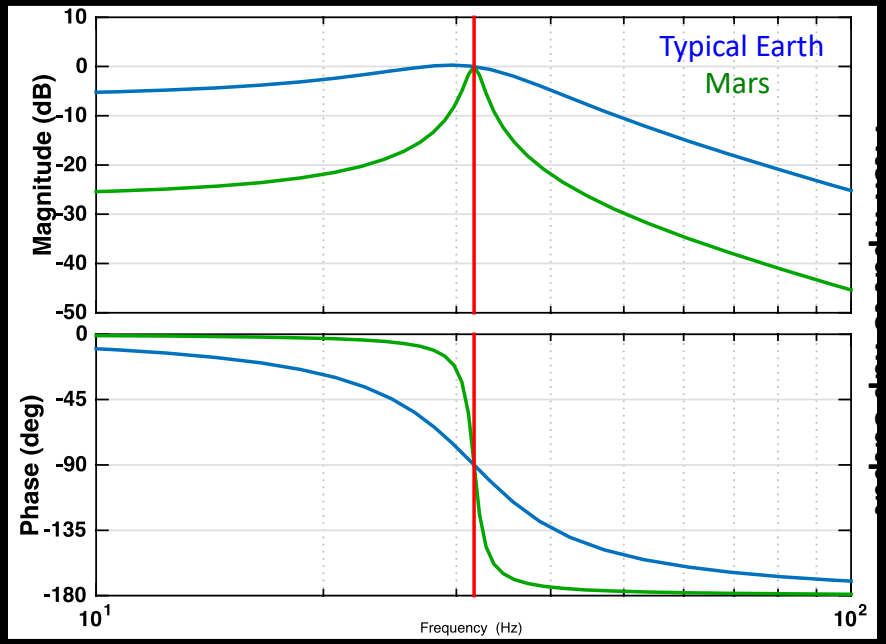
Dec 2014
Rotor-on-joystick

Rotor – with a joystick

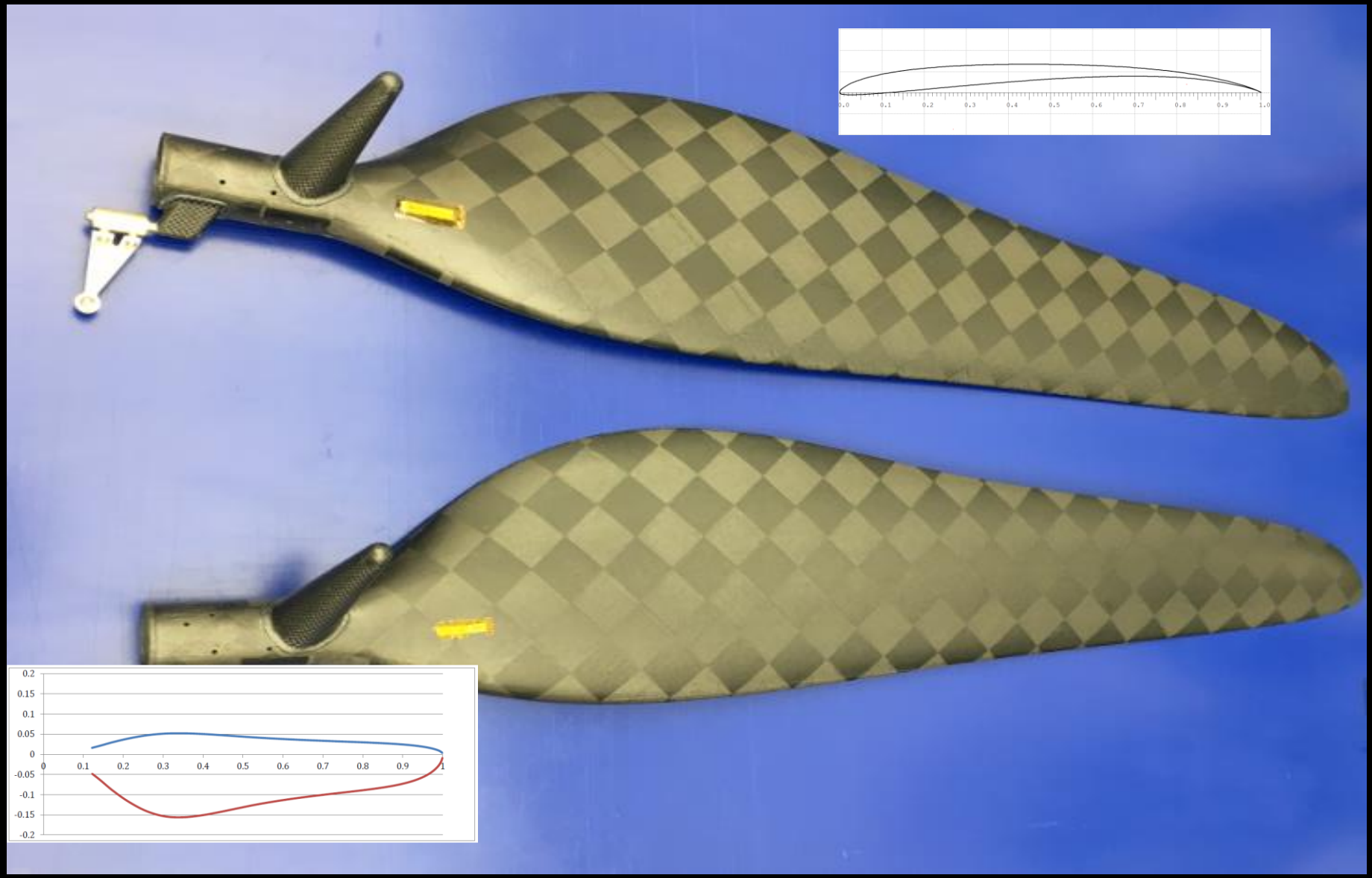


Blade flapping matters ….

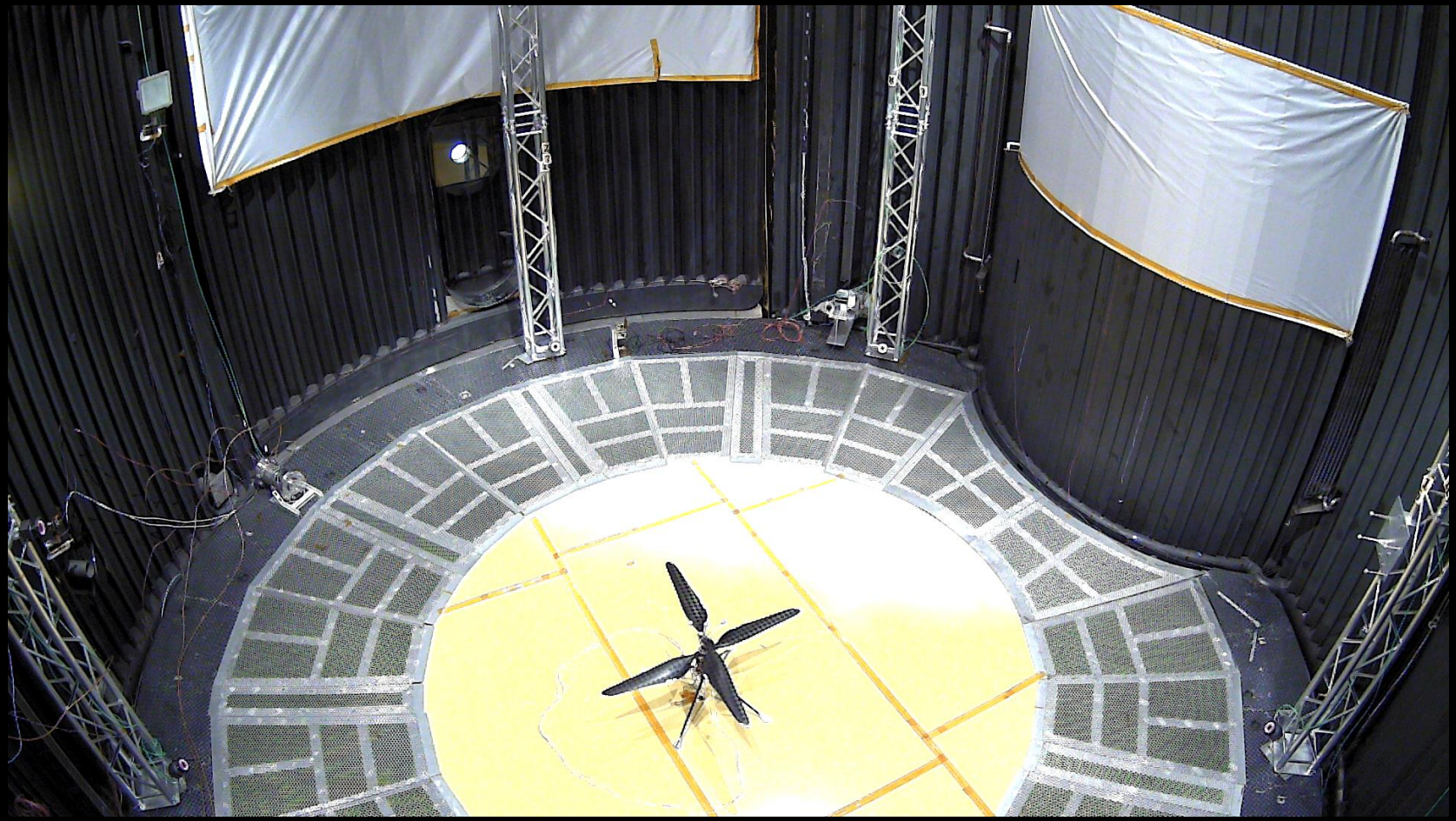
- Flap damping is aerodynamic
- Dramatically reduced damping because of 1% Earth density
- Un-damped modes interfere with control



Rotor – a very special design

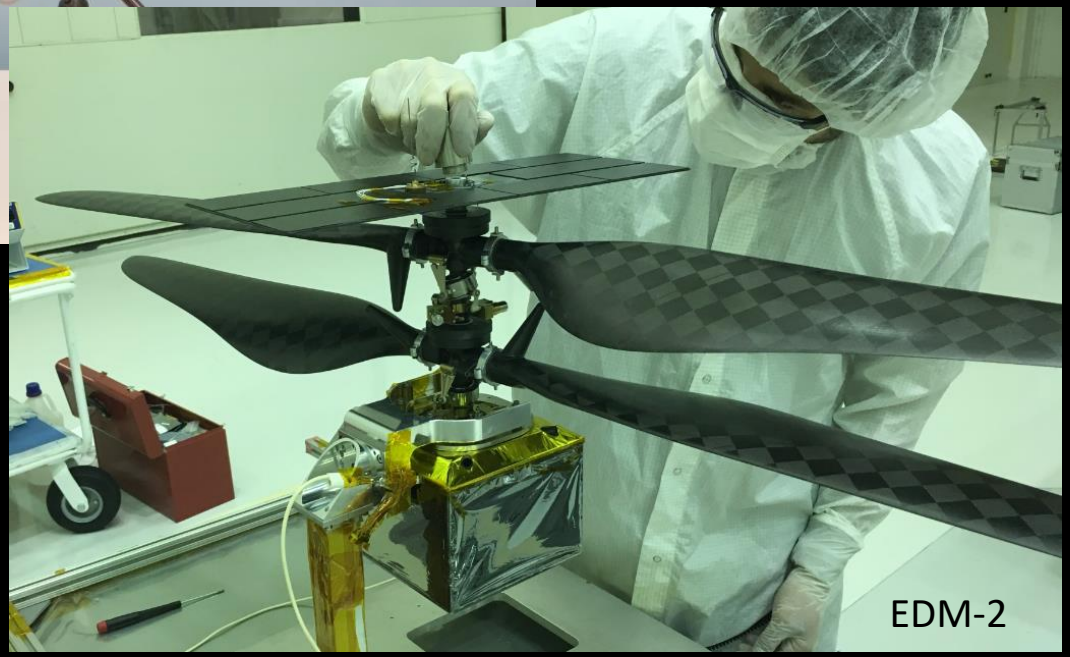


Rotor – under control !



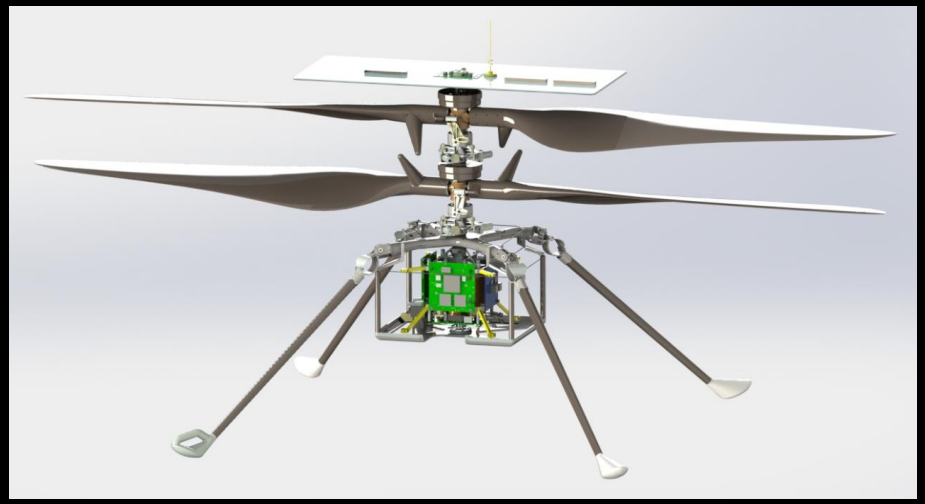
Can you survive ?
Shock, vibration and thermal tests

Can you fly ?
Flight dynamics identification and flight tests



Flight Model (FM) Mars Helicopter

- 1.21m diameter rotor
- 1.8kg total mass
- Autonomous flight through ground-commanded way-points
- Powered by 6-cell Lithium-Ion battery
- Battery recharged by solar panel mounted above the rotors during day
- Designed for five 90-second flights at altitudes up to 10m
- Qualified for space flight



Rotorcraft Designs

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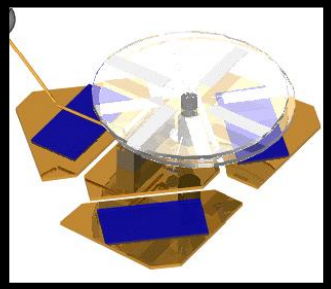
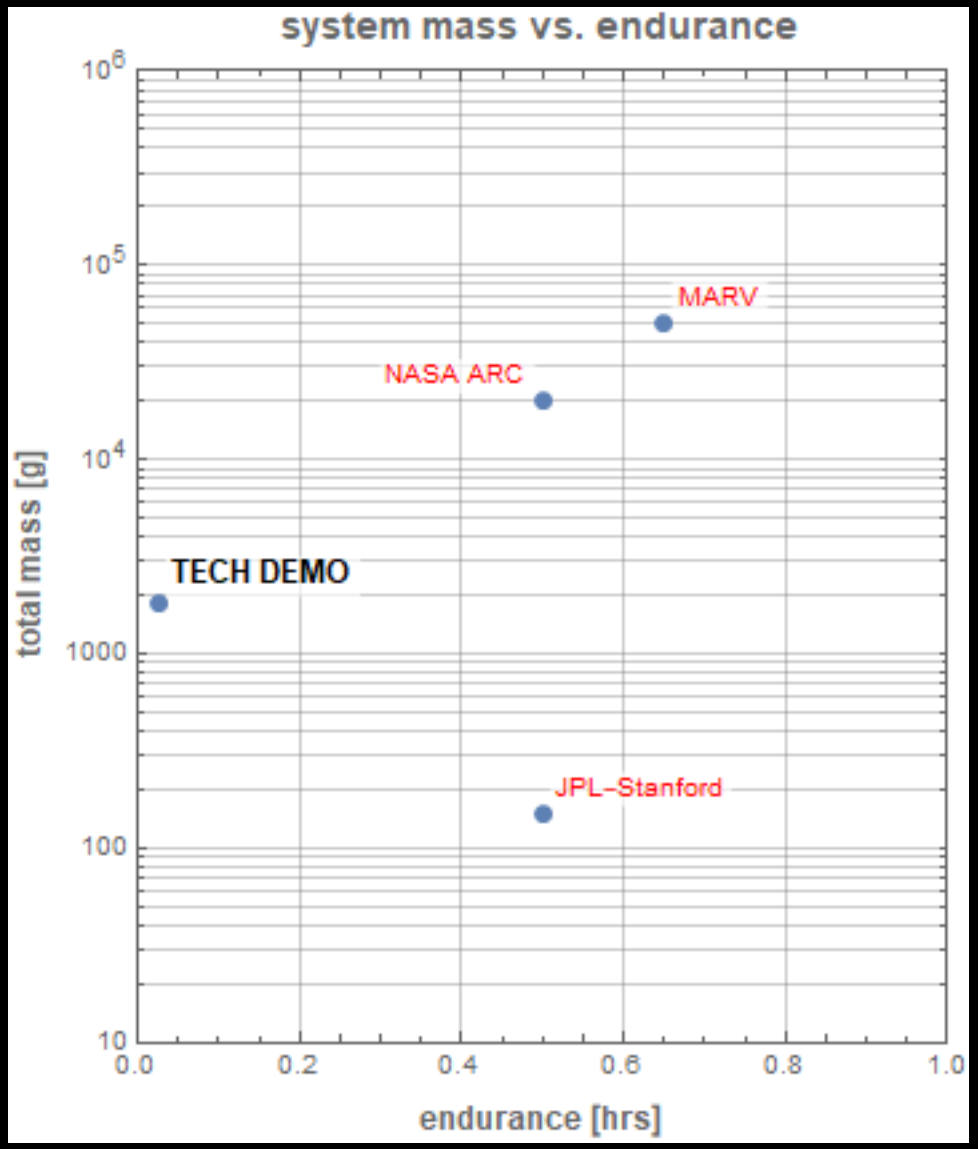
2000-2005
R_{eff} = 1.7m



Mars Helicopter Tech Demo
2020
R_{eff} = 0.6m



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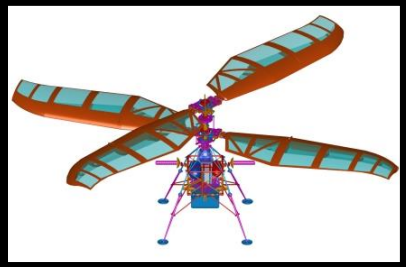

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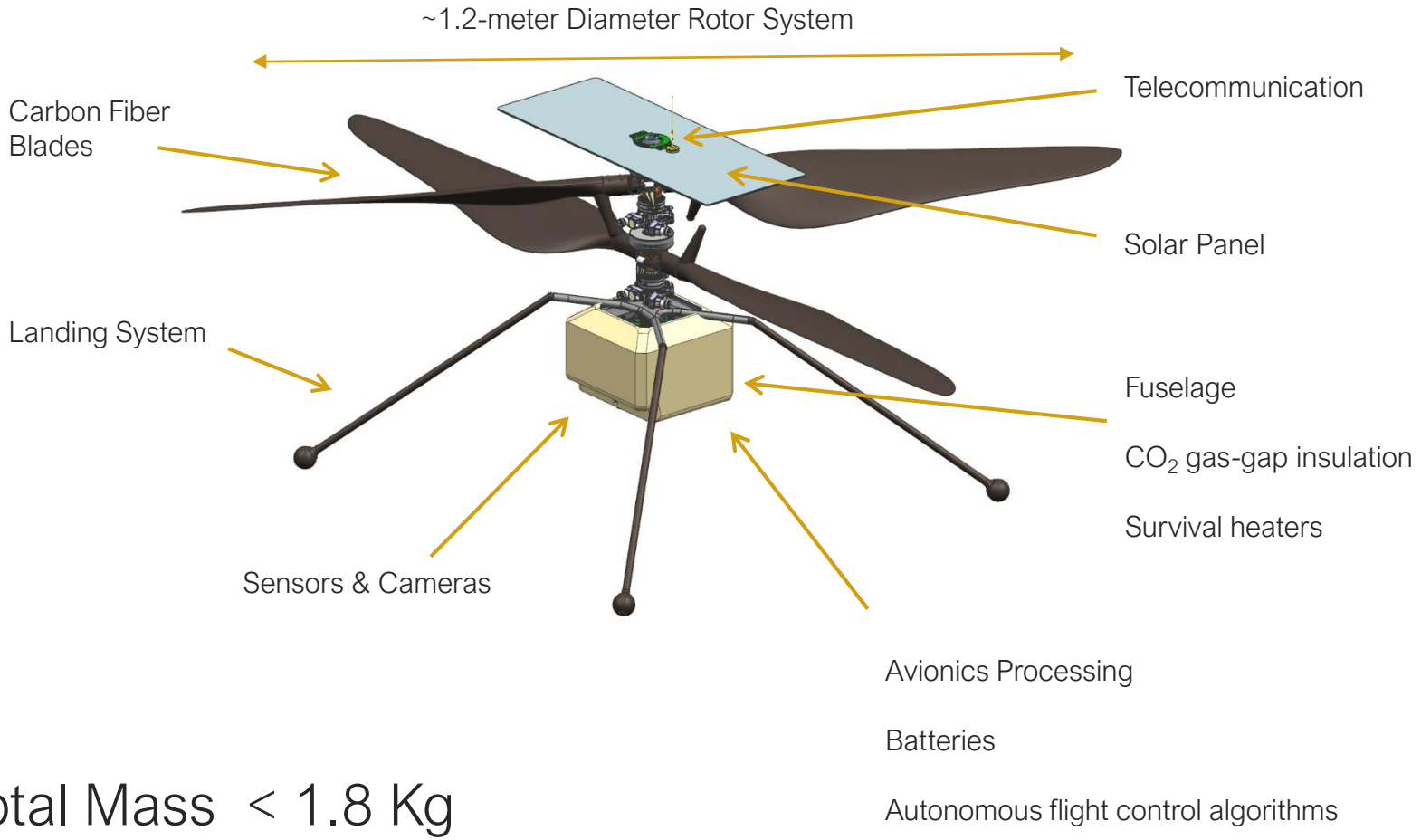
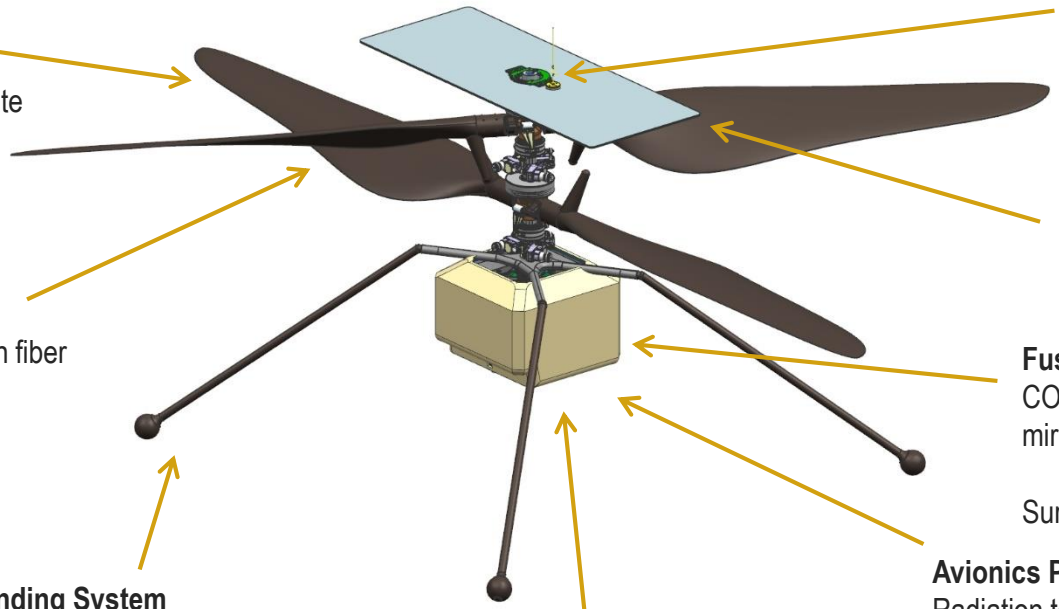
Mars Helicopter Design



- ✓ Total Mass < 1.8 Kg
- ✓ Rotor Speed: 1900-2800 RPM
- ✓ Blade Tip Mach Number: < 0.7

Technologies in a Mars Helicopter



Rotor System
Brushless motors for rotor
Brushed motors for swashplate collective / cyclic

Blades
Lightweight carbon fiber

Landing System
Lightweight legs for landing on terrain

Telecommunication
COTS chipset
Two node network
802.15.4 protocol (ZigBee)

Solar Panel
Inverted Metamorphic Quadruple Junction (IMM4) solar cells

Fuselage
CO_2 gas-gap insulation – dark mirror kapton film skin technology

Survival heaters

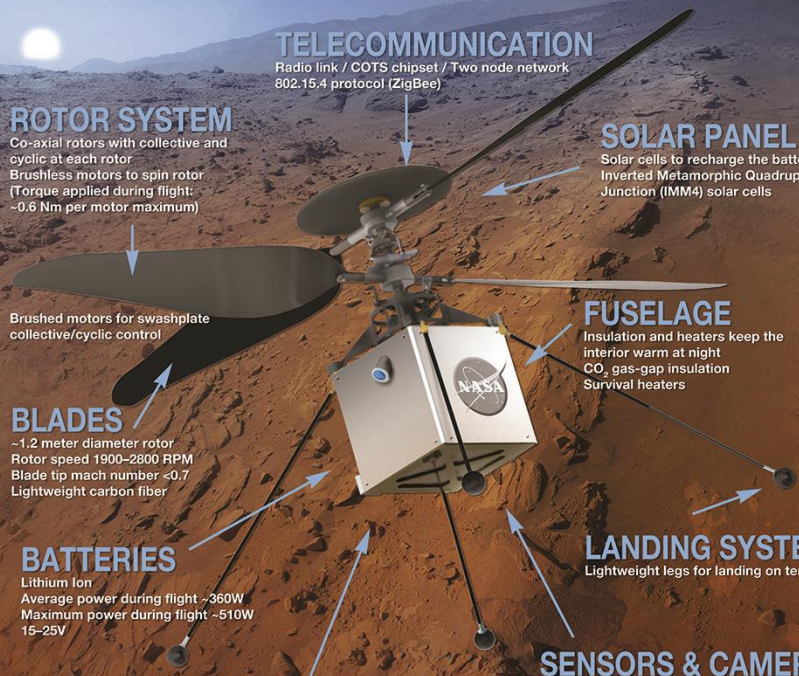
Avionics Processing
Radiation tolerant Field Programmable Gate Array (FPGA)
Dual-redundant automotive-grade processors
Navigation processor

Autonomous flight control algorithms

Sensors & Cameras
MEMS IMU
Laser Altimeter
Inclinometer
133˚x100˚ FOV Navigation camera
13 Mpixel 56˚x42˚ FOV color camera for pictures of terrain

Total Mass < 1.8 Kg
Rotor Speed: 1900-2800 RPM
Blade Tip Mach Number: < 0.7

ANATOMY OF A MARS HELICOPTER



TELECOMMUNICATION
Radio link / COTS chipset / Two node network
802.15.4 protocol (ZigBee)

ROTOR SYSTEM
Co-axial rotors with collective and cyclic at each rotor
Brushless motors to spin rotor
(Torque applied during flight: ~0.6 Nm per motor maximum)

Brushed motors for swashplate collective/cyclic control

SOLAR PANEL
Solar cells to recharge the battery
Inverted Metamorphic Quadruple Junction (IMM4) solar cells

FUSELAGE
Insulation and heaters keep the interior warm at night
CO_2 gas-gap insulation
Survival heaters

BLADES
~1.2 meter diameter rotor
Rotor speed 1900–2800 RPM
Blade tip mach number <0.7
Lightweight carbon fiber

BATTERIES
Lithium Ion
Average power during flight ~360W
Maximum power during flight ~510W
15–25V

LANDING SYSTEM
Lightweight legs for landing on terrain

AVIONICS PROCESSING
Autonomous flight guidance, navigation & control on fault tolerant computing architecture
Autonomous flight control algorithms
Radiation tolerant field programmable dual-redundant automotive-grade processors
Navigation processor

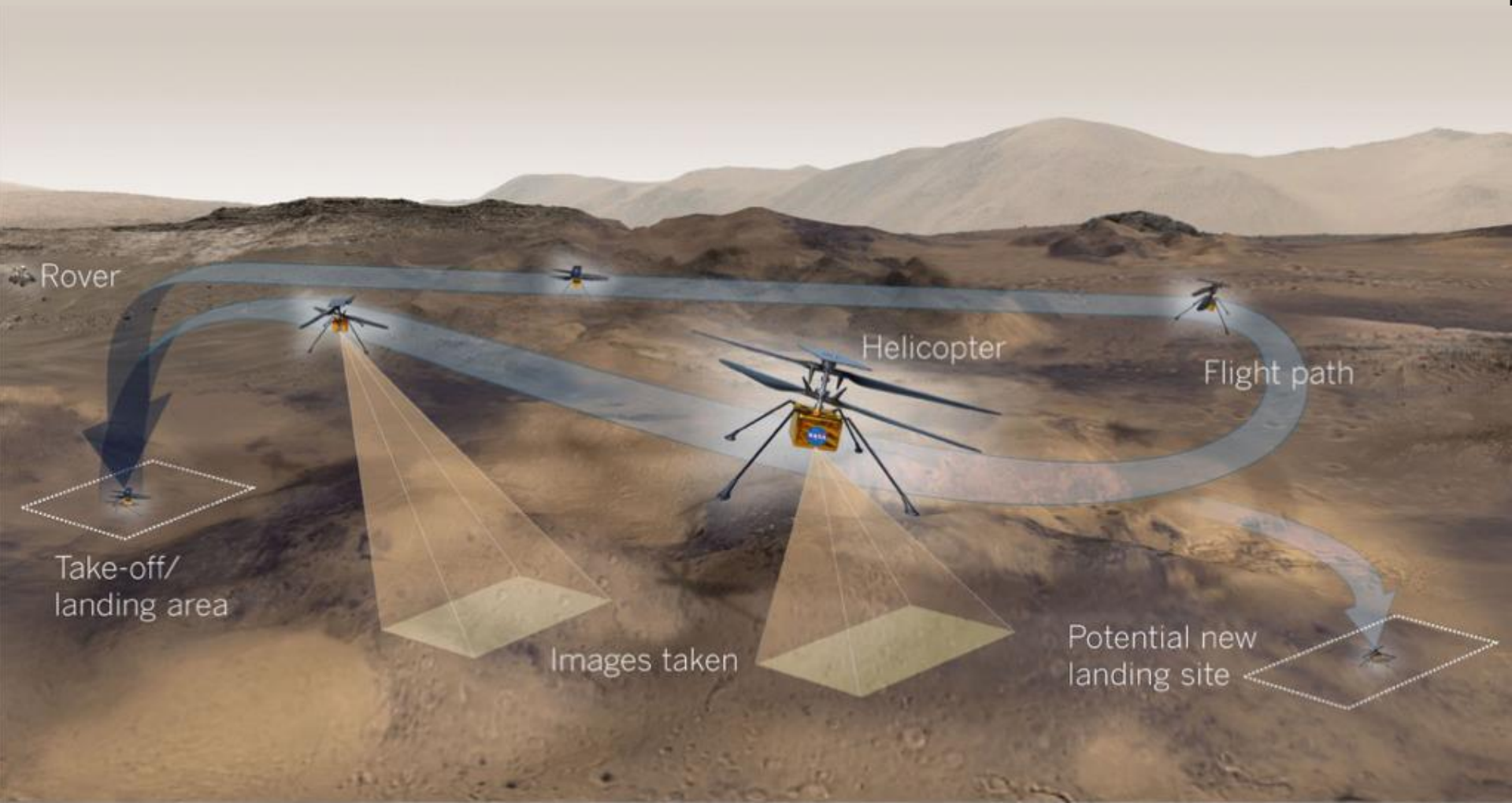
SENSORS & CAMERAS
MEMS IMU / Laser Altimeter / Inclinometer / Accelerometers / Gyros
133° x 100° FOV navigation camera /
13 Mpixel 56° x 42° FOV color camera for pictures of the terrain

Total Mass <1.8 Kg

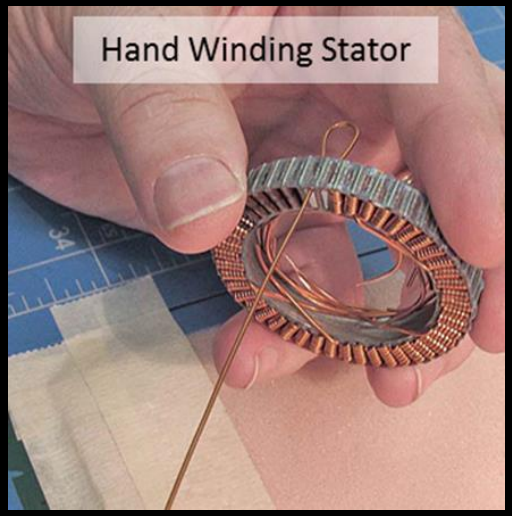
MARS FLIGHT ENVIRONMENT
Atmospheric density: ~1% of Earth
Reynolds Number at 0.75R: 9000 — 15000
Temperatures: -50°C to -25°C
Gravity: ~3.71 m/s2 (~40% of Earth)

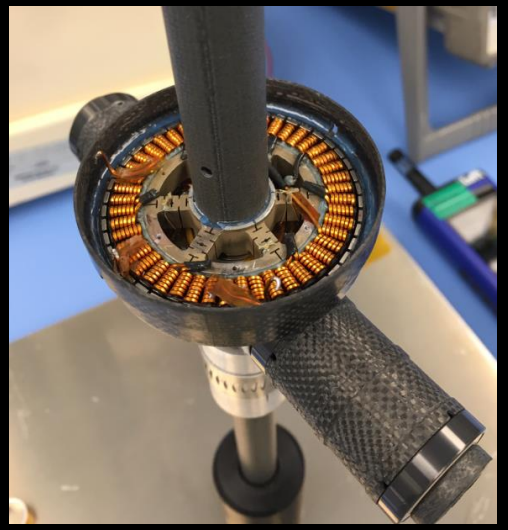
National Aeronautics and Space Administration

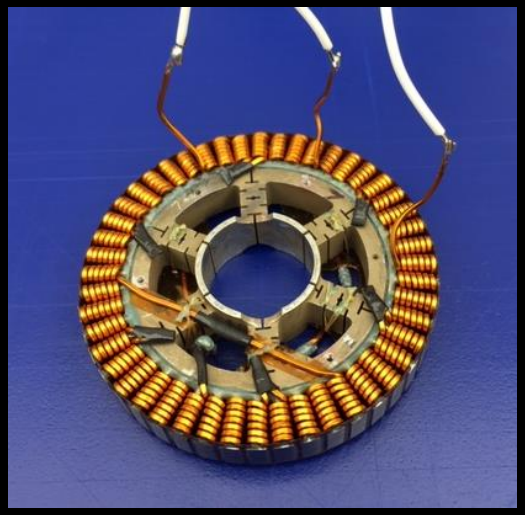
At Mars

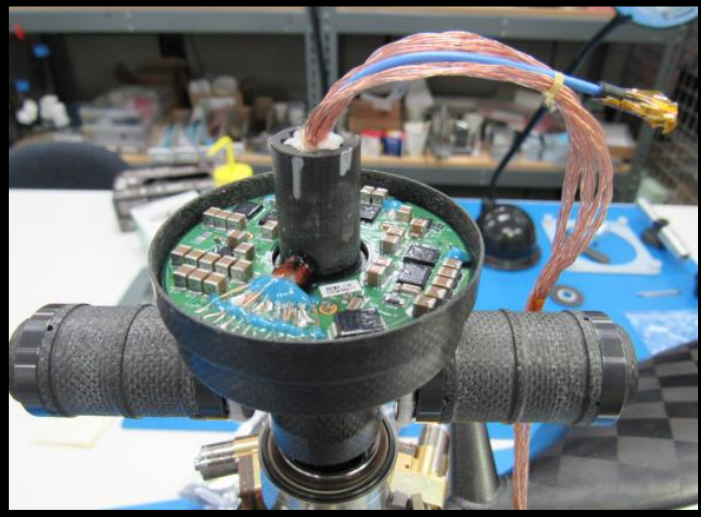

Rover
Helicopter
Flight path
Take-off/
landing area
Images taken
Potential new
landing site

Propulsion Motor

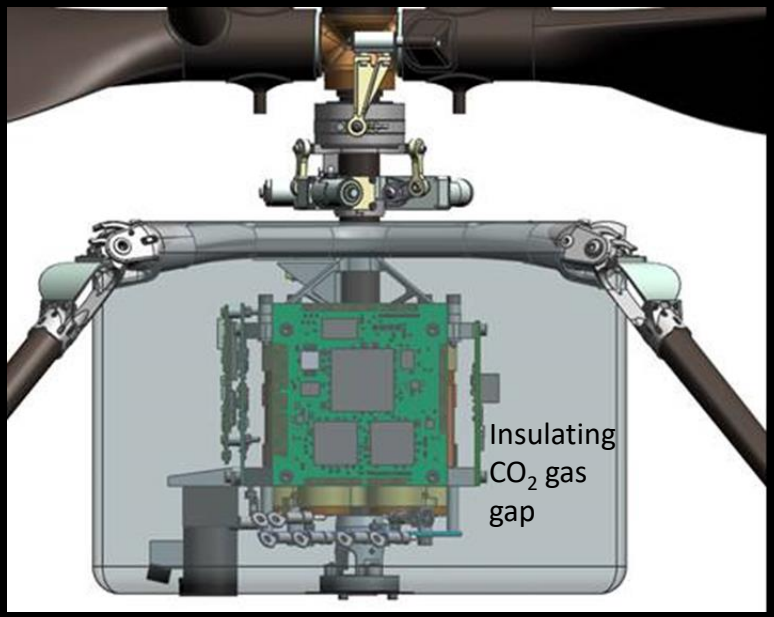


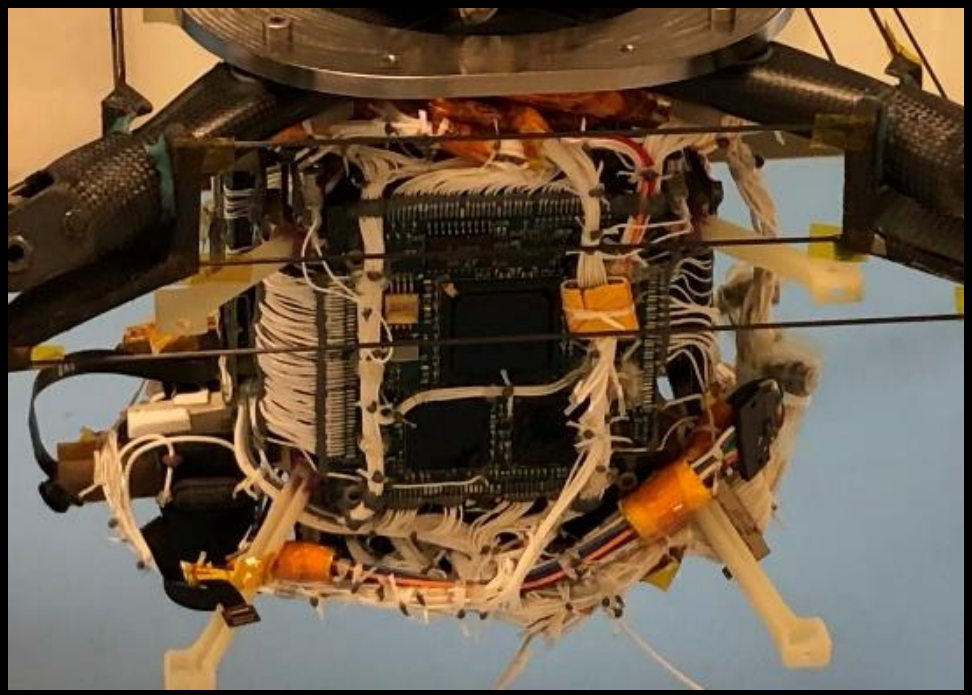




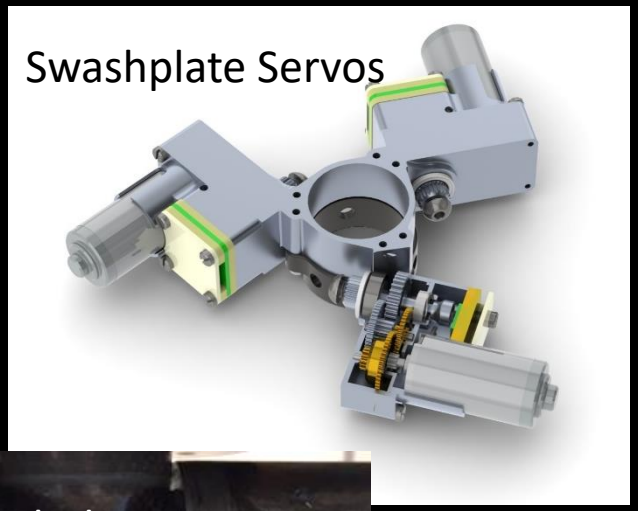


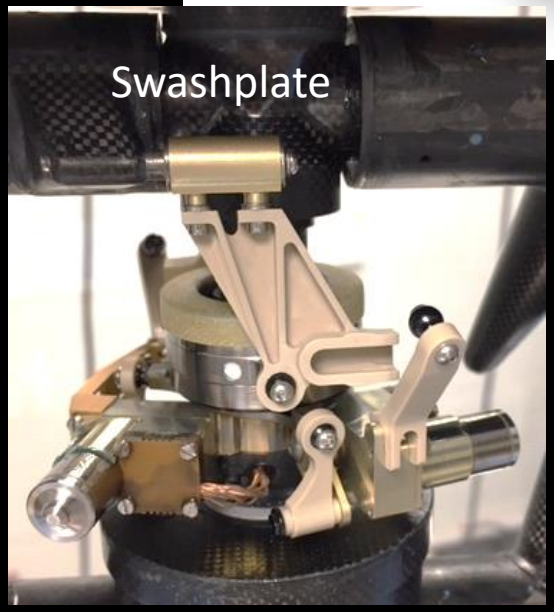
Electronics, Fuselage & Insulation

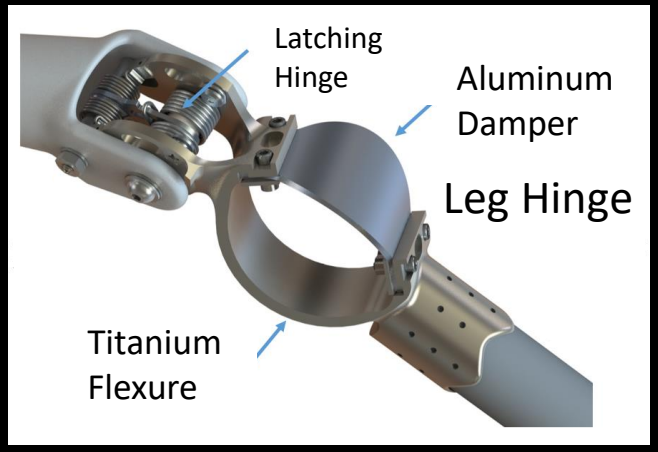




Mechanical Elements

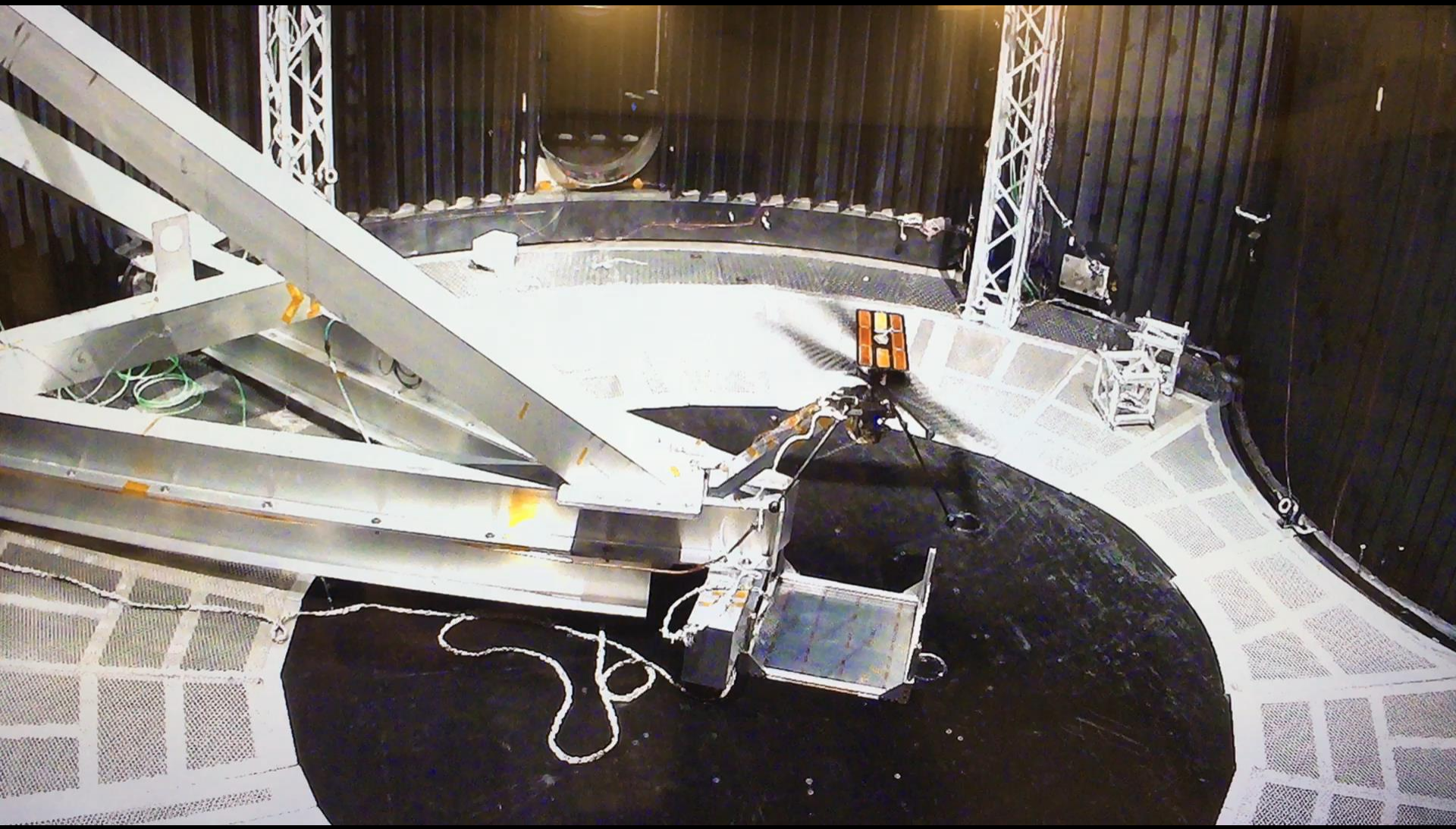




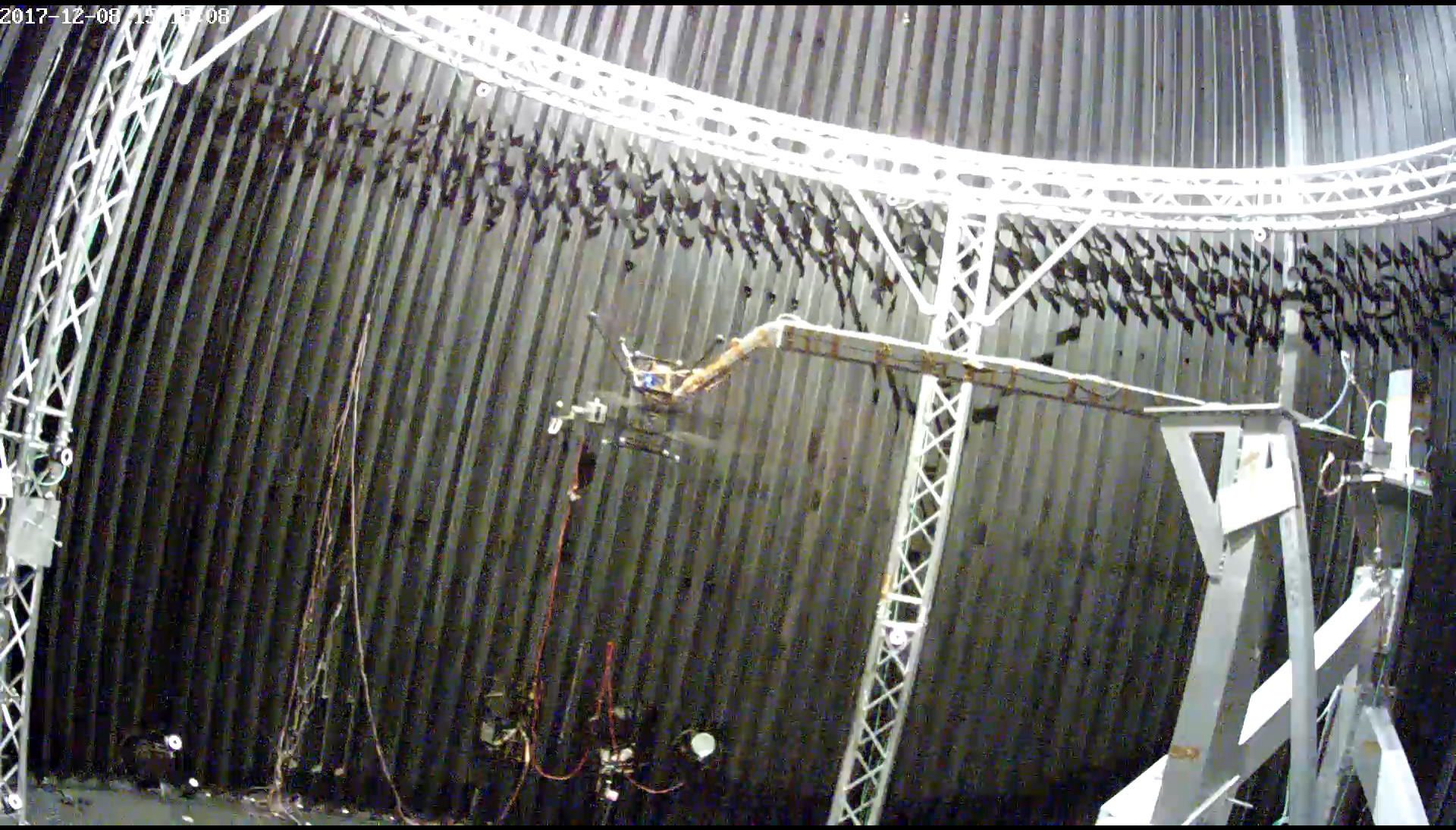


Tests

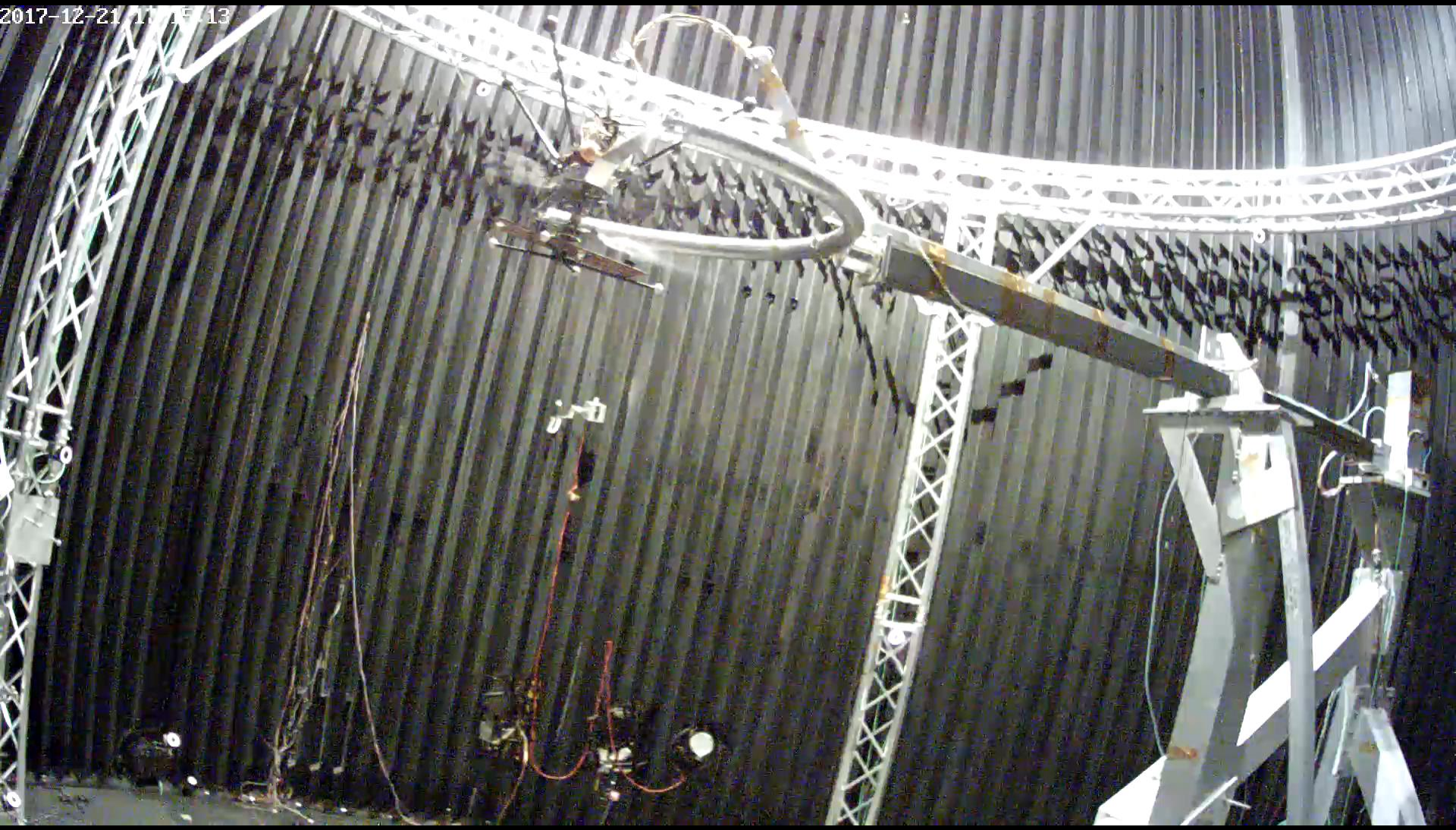
Structure dynamics in vacuum



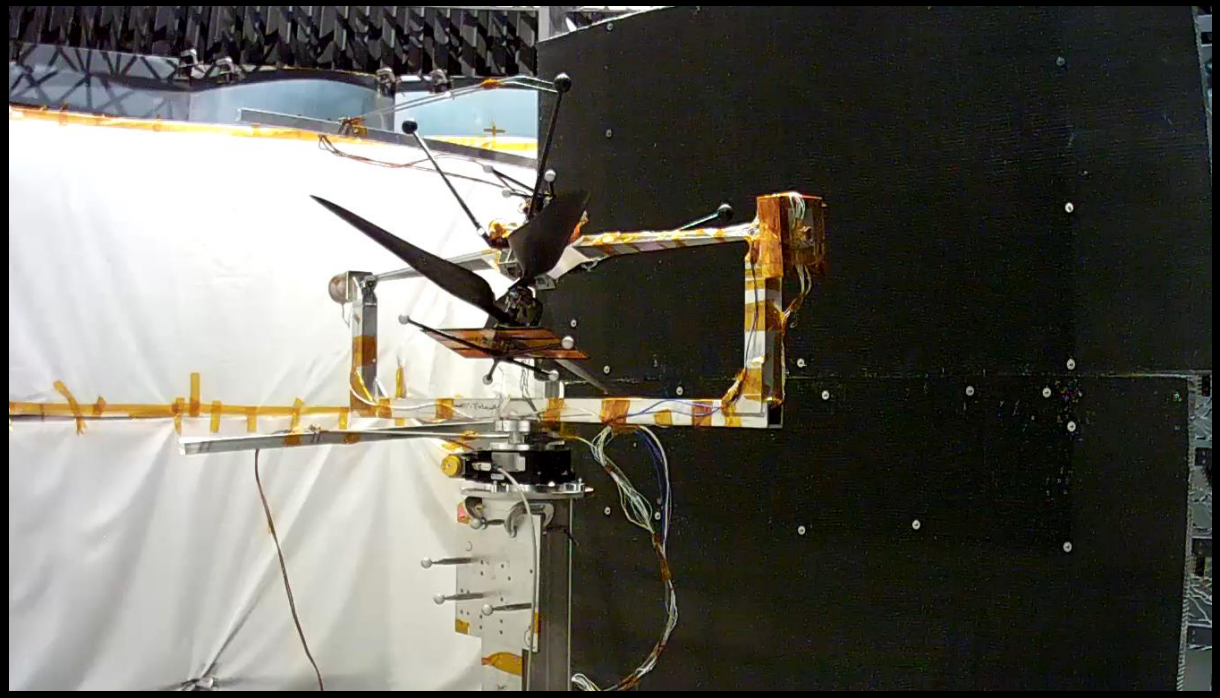
Translational dynamics in atmosphere



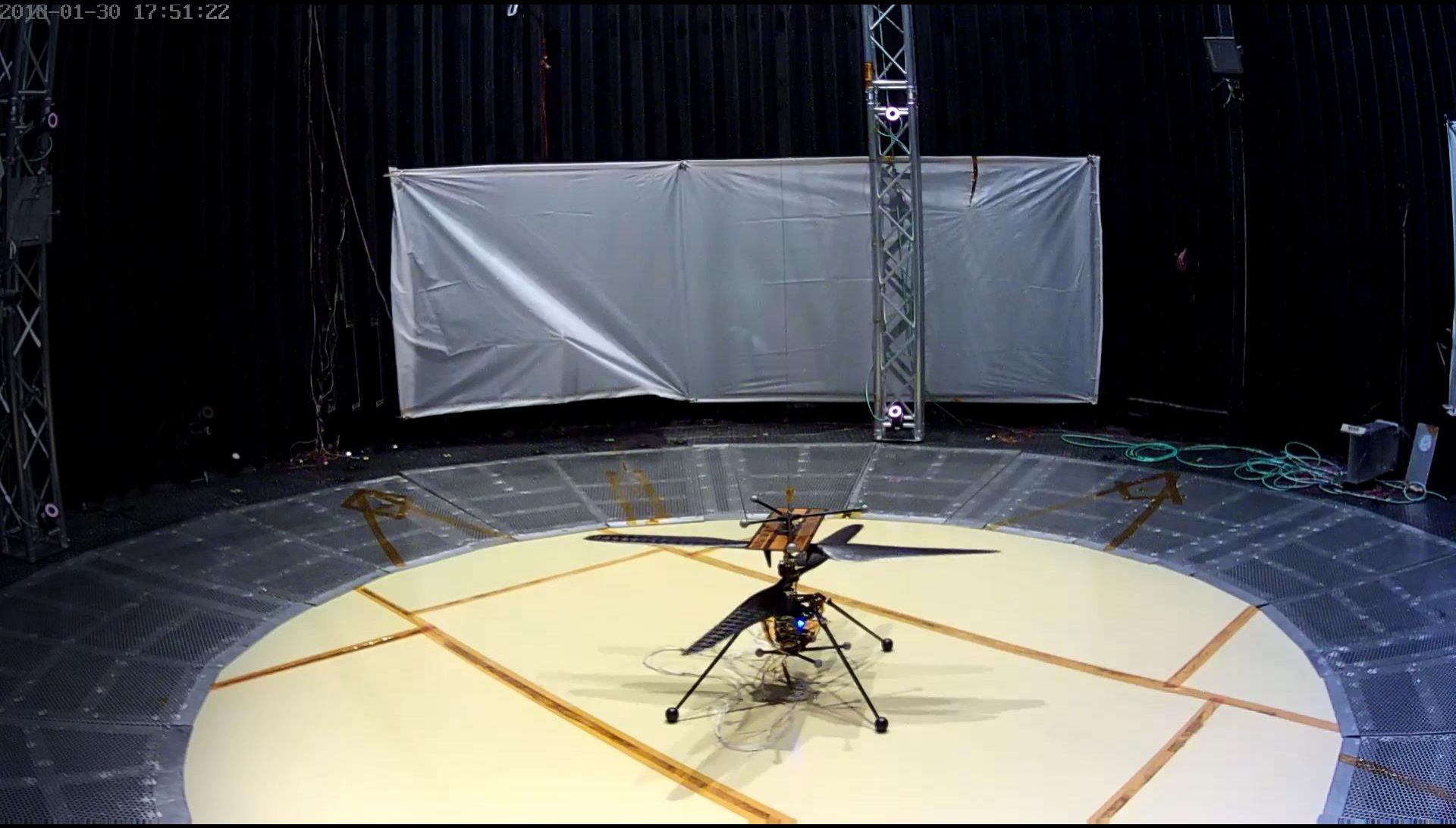
Rotational dynamics in atmosphere



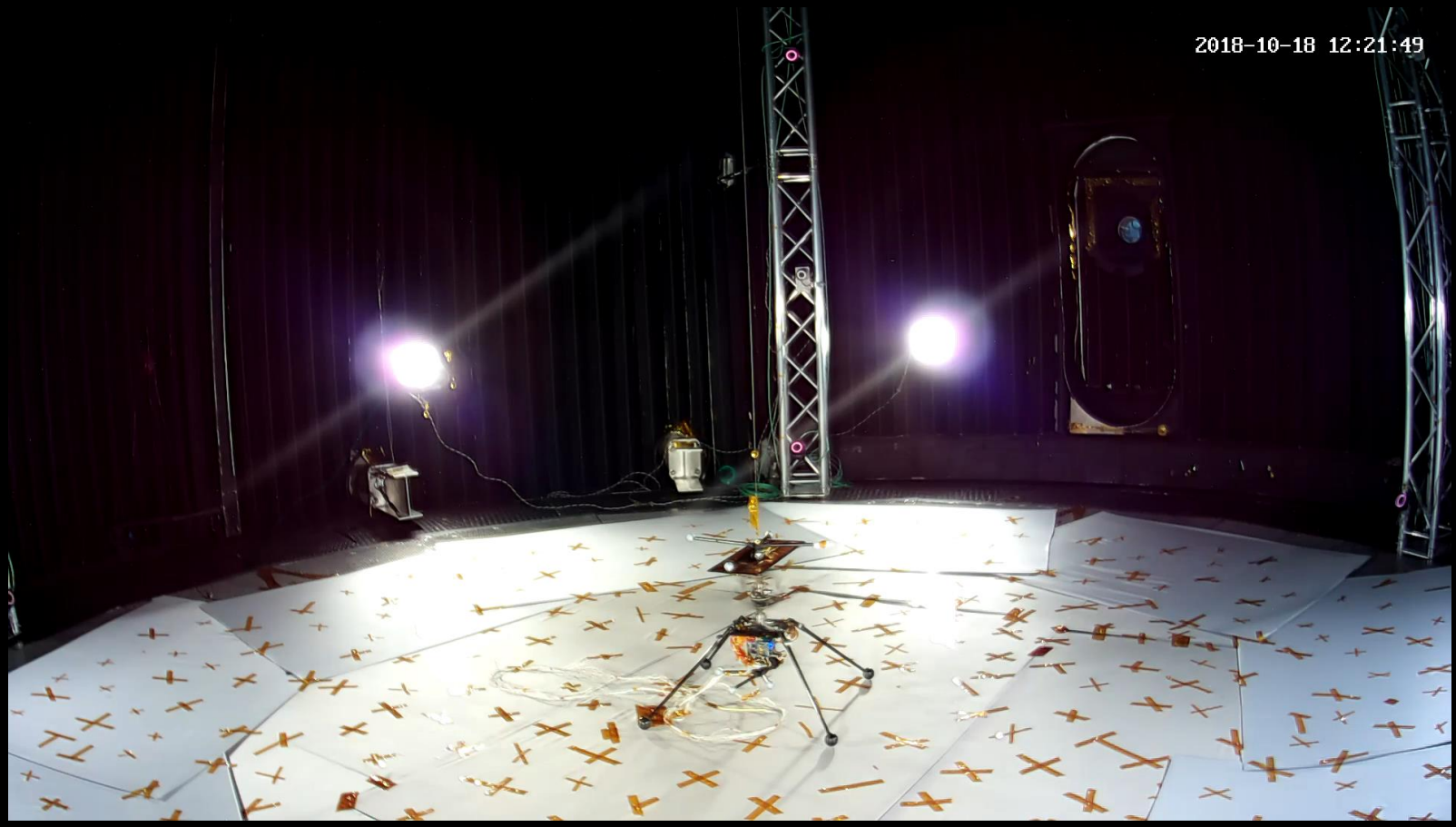
Dynamics with winds



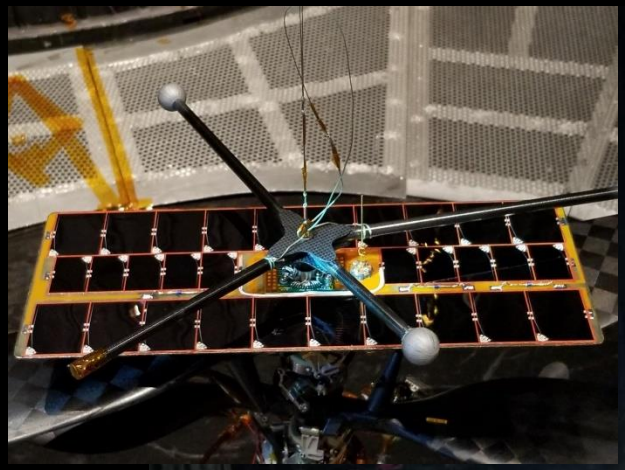
Flight in Mars-like Atmosphere



Navigation & Sensor Control Tests

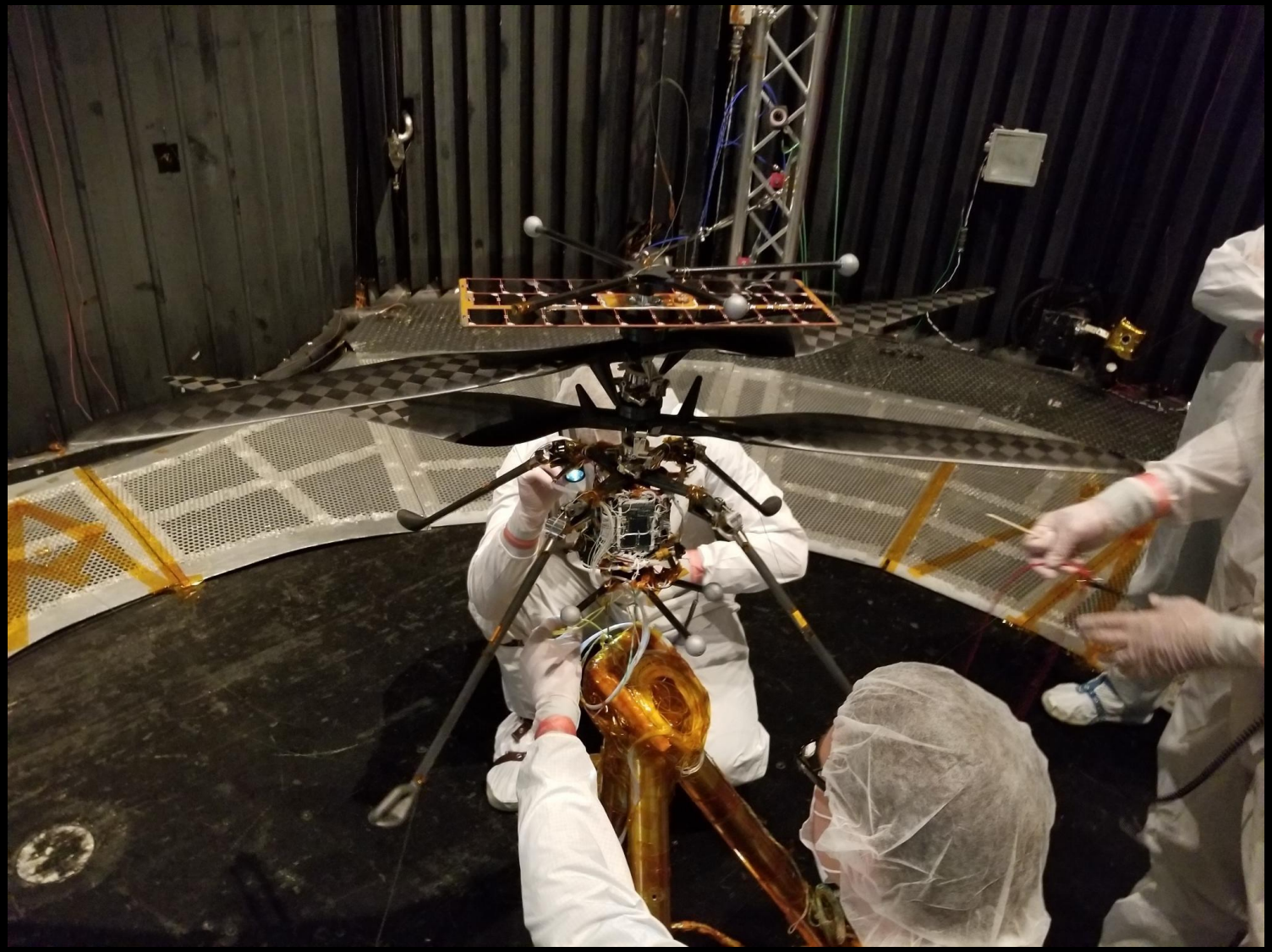


Solar illumination on array

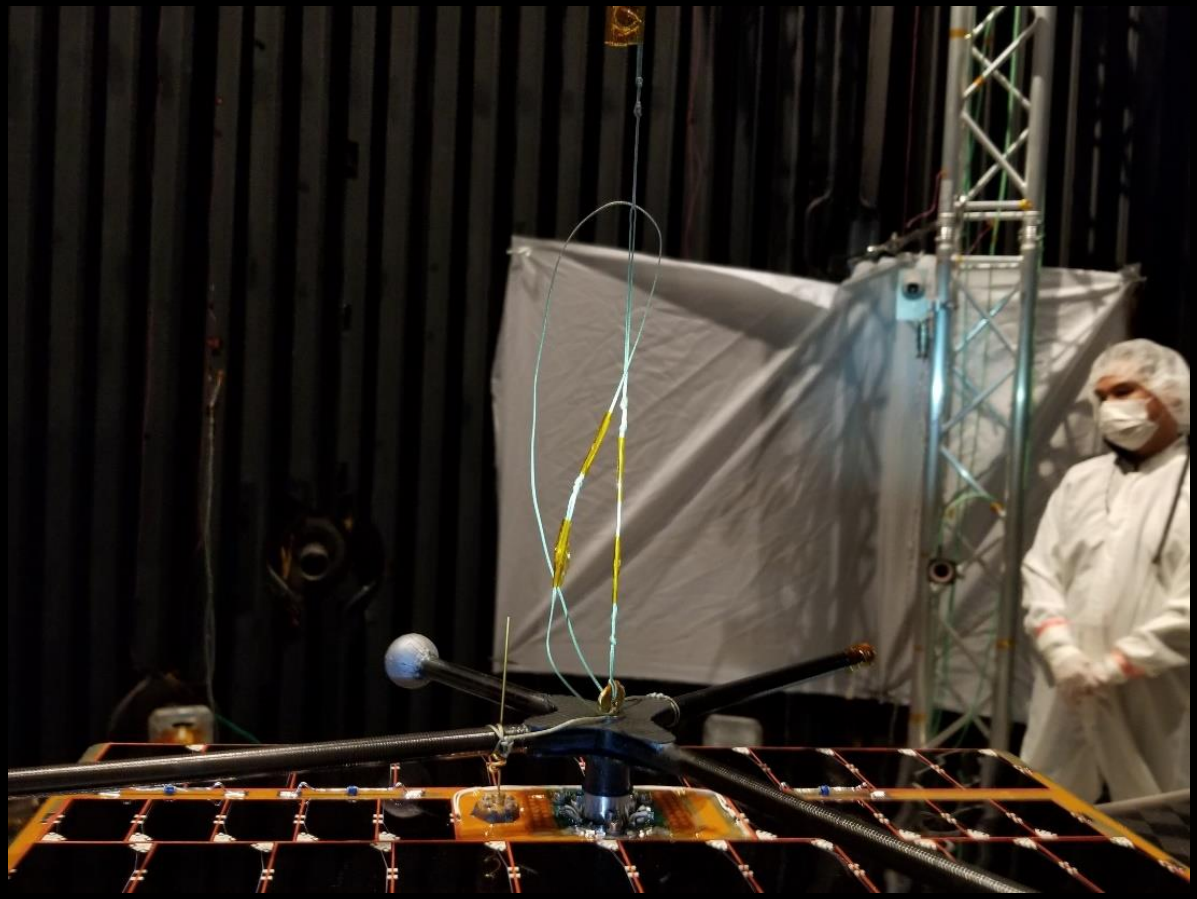


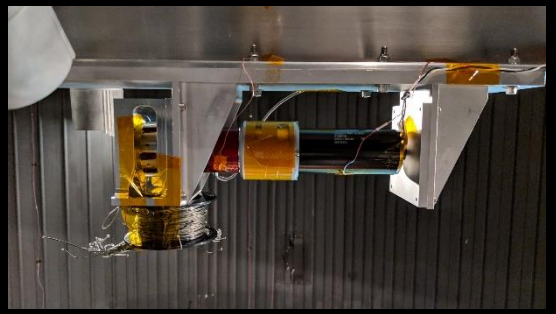
Camera checks

Mechanical checks



Gravity compensation

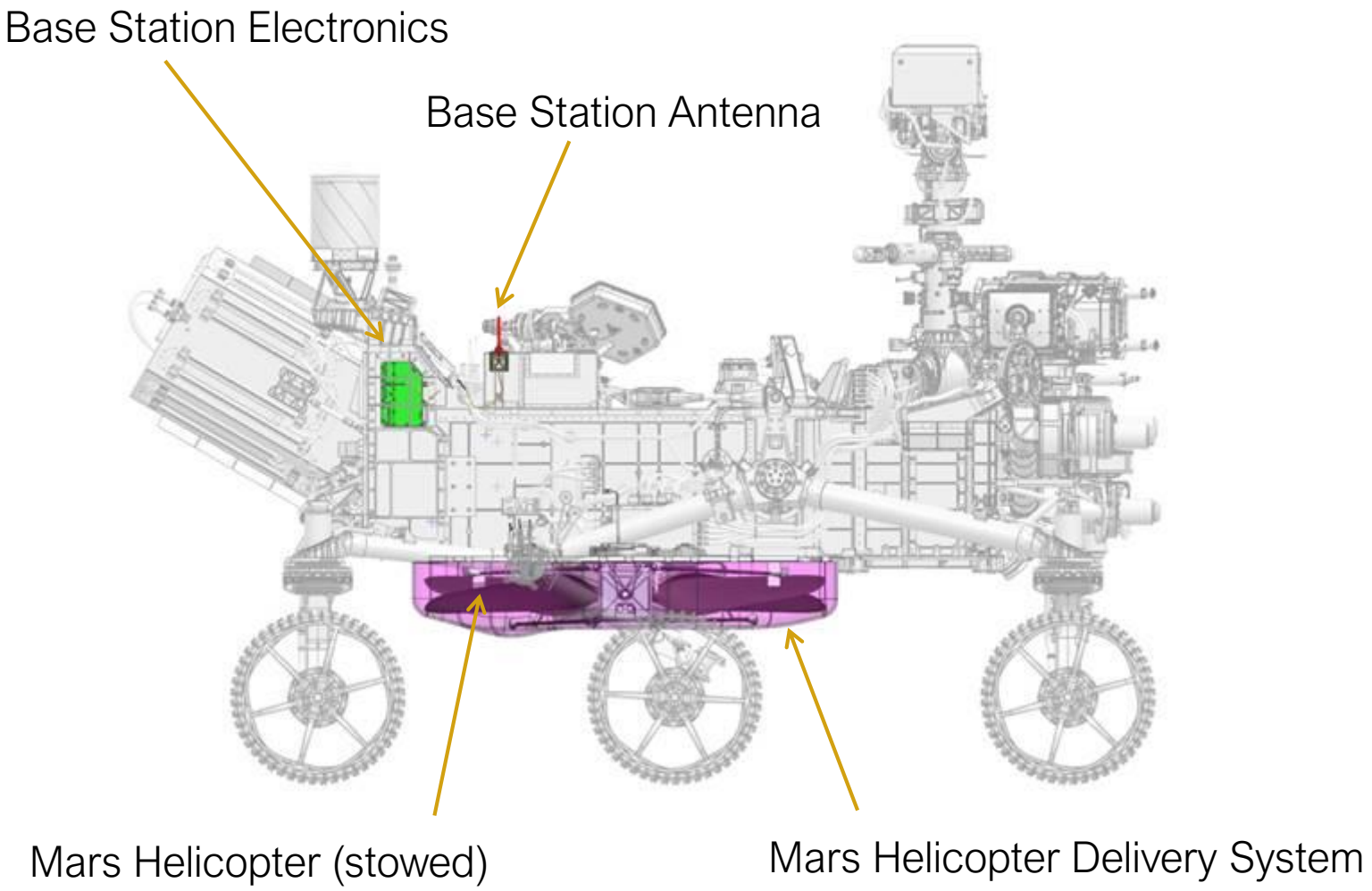




Getting ready for launch

Hitching a Ride

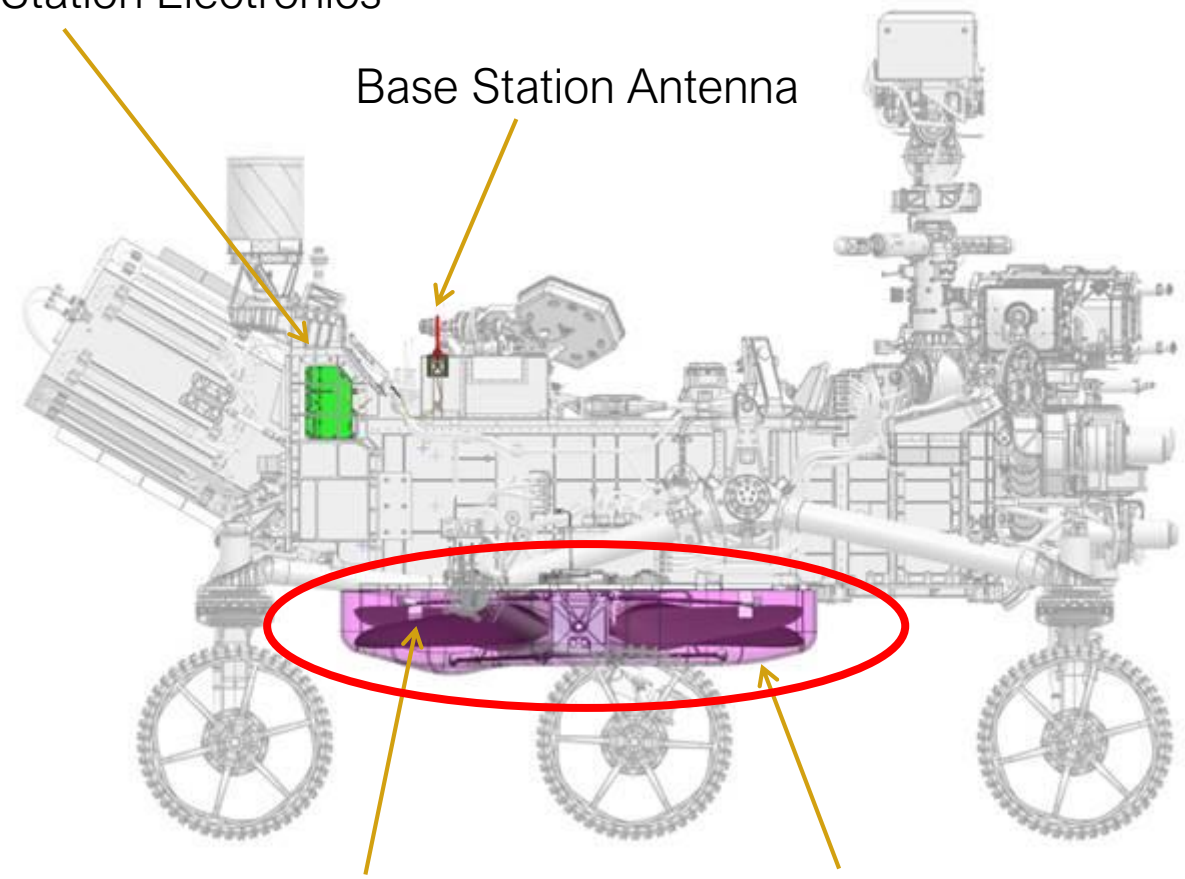
Mars Helicopter Accommodation on Mars 2020 Rover



Getting ready for integration

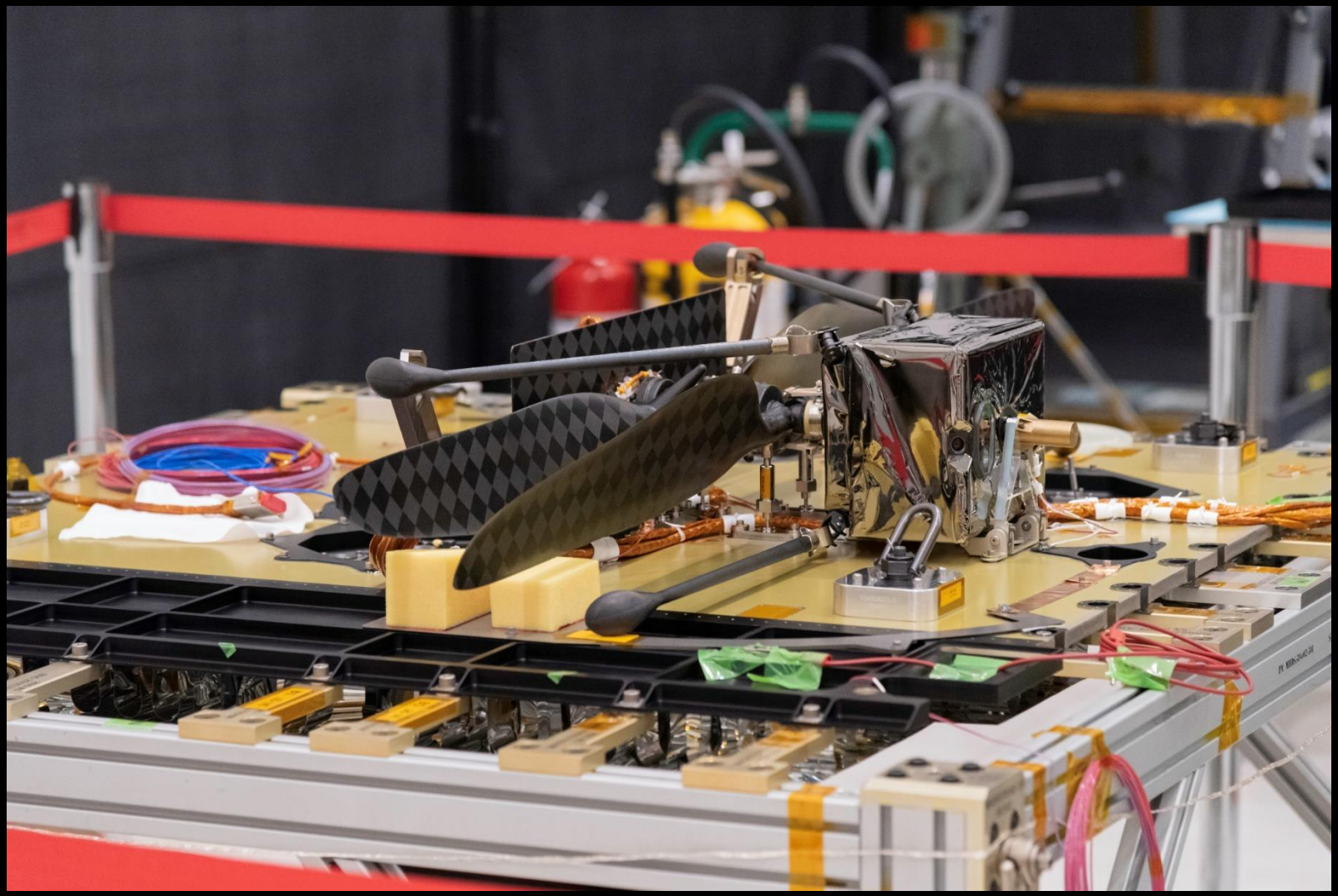
Delivery

Hitching a Ride



Integrating with deployment system

Integrating with deployment system



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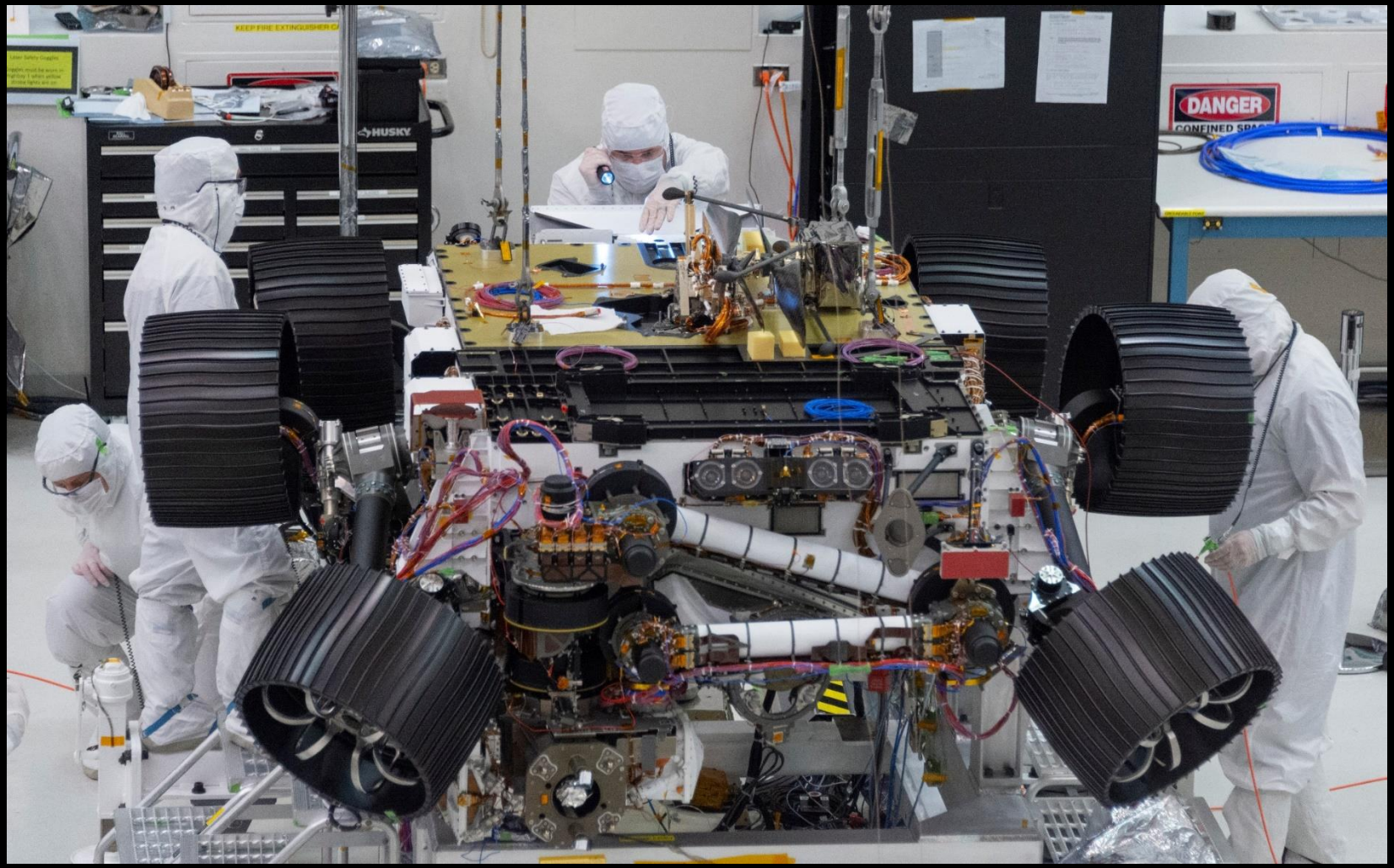
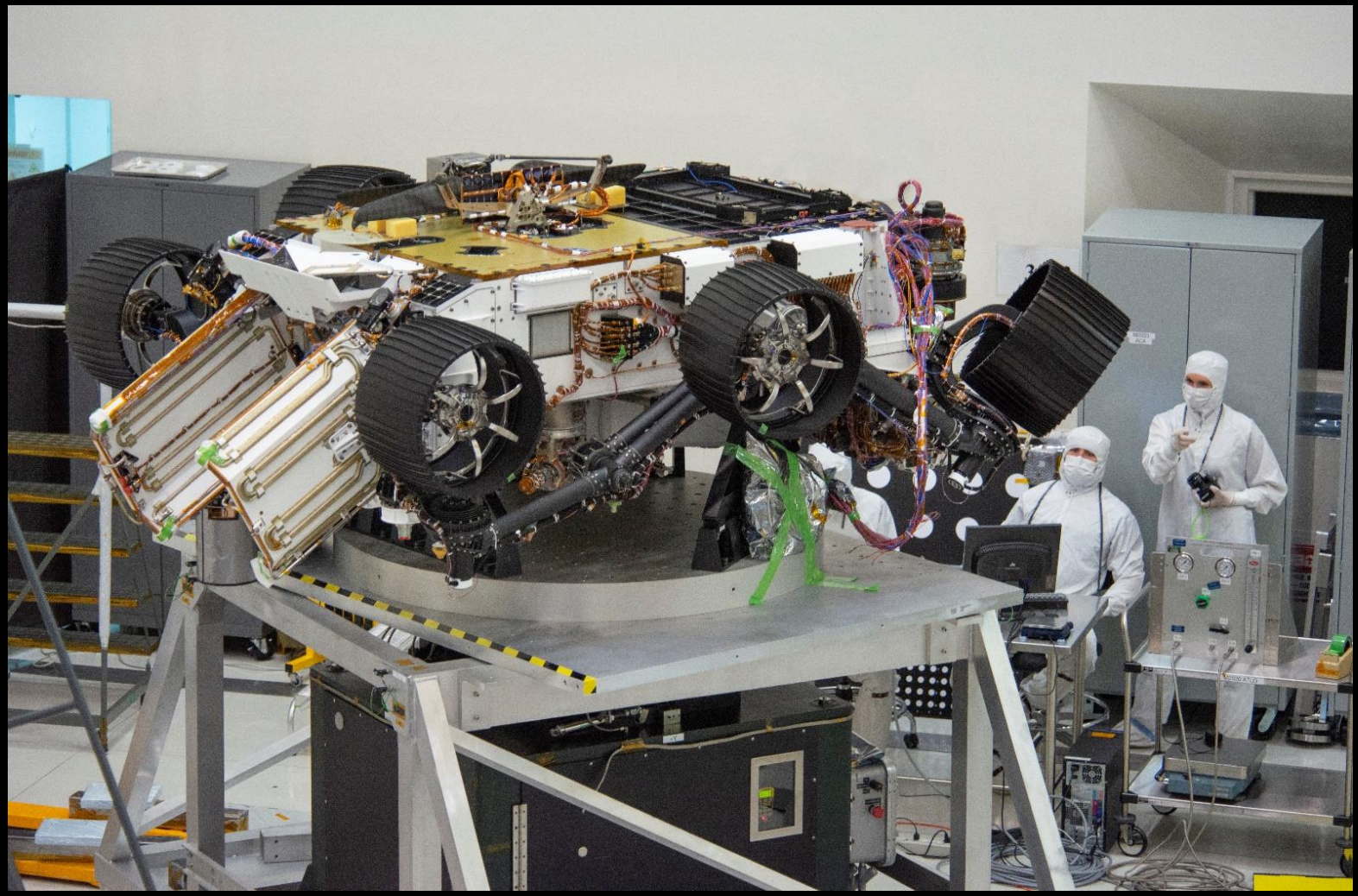


Integrating with deployment system



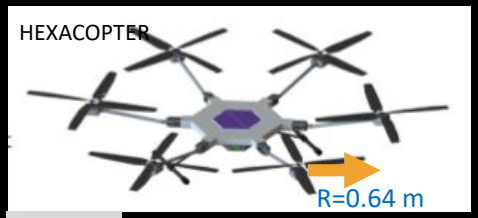
Future Helicopter Designs

Tech Demo Design

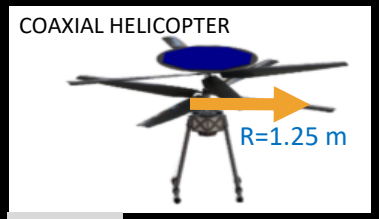
1.8 kg

New Designs

Payload 2-4 kg;
Range 2 km
Speed 30 m/s
Hover 4.5 minutes



~20 kg



~19 kg

Advanced Tech Demo Design

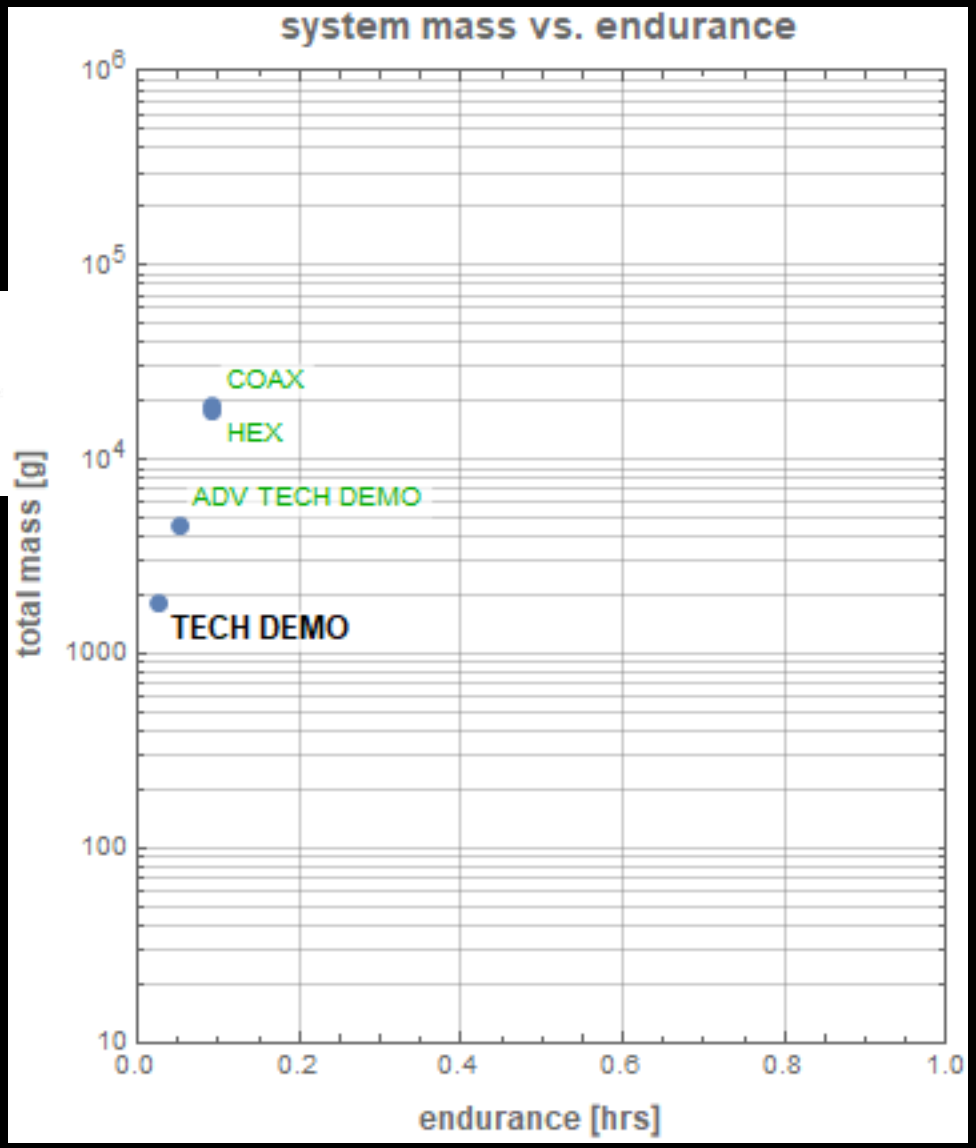
Payload ~1 kg;
Range 2 km
Speed 30 m/s
Hover 2 minutes

4.6 kg

Rotorcraft Designs

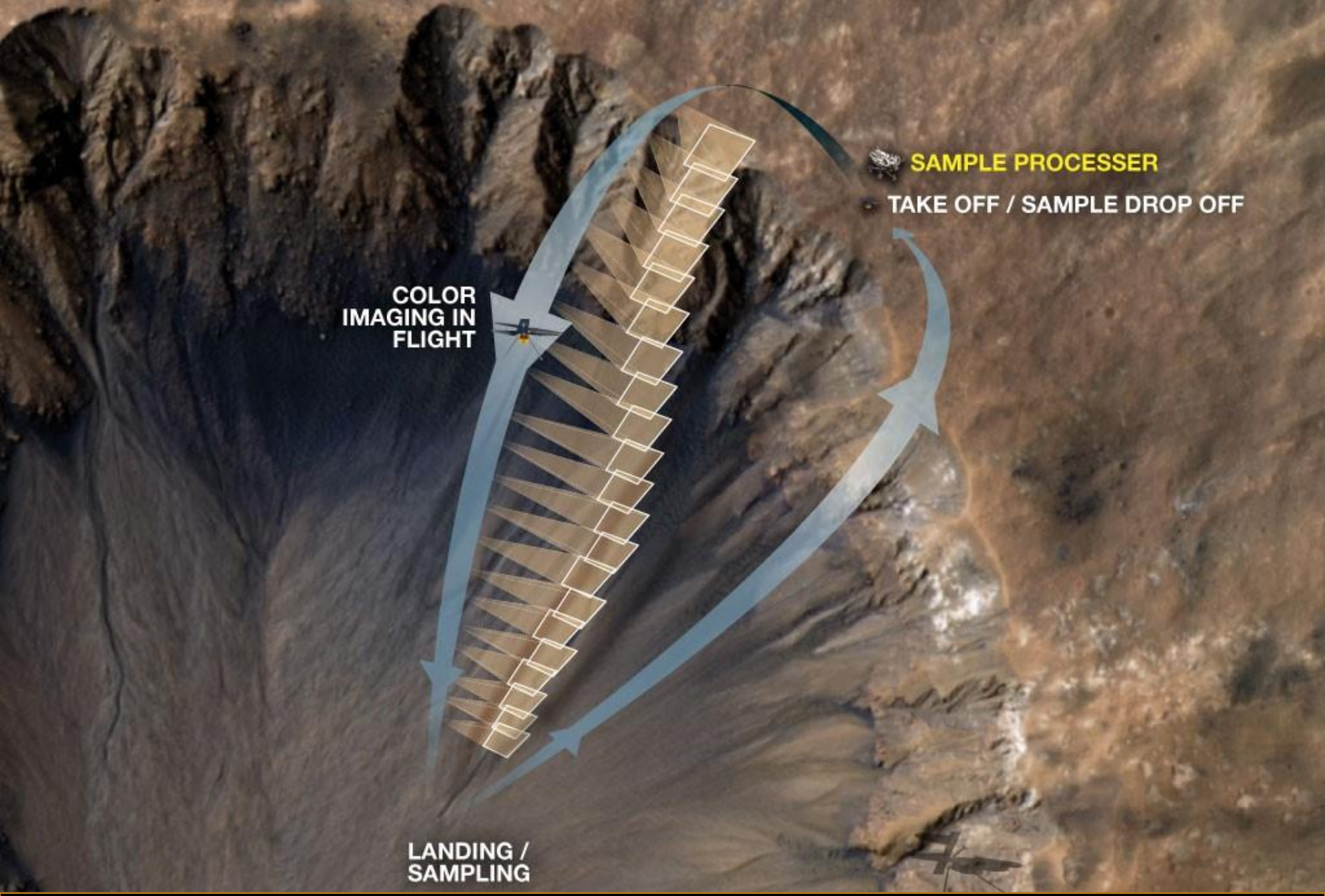
HEX
2020+
R_{eff} = 1.57m

Mars Helicopter
Tech Demo
2020
R_{eff} = 0.6m



COAX
2020+
R_{eff} = 1.25m

Mars Helicopter
Adv Tech Demo
2020+
R_{eff} = 0.6m



Example of a future science mission concept